Transport and Greenhouse: Costs and Options for Reducing Emissions

Report

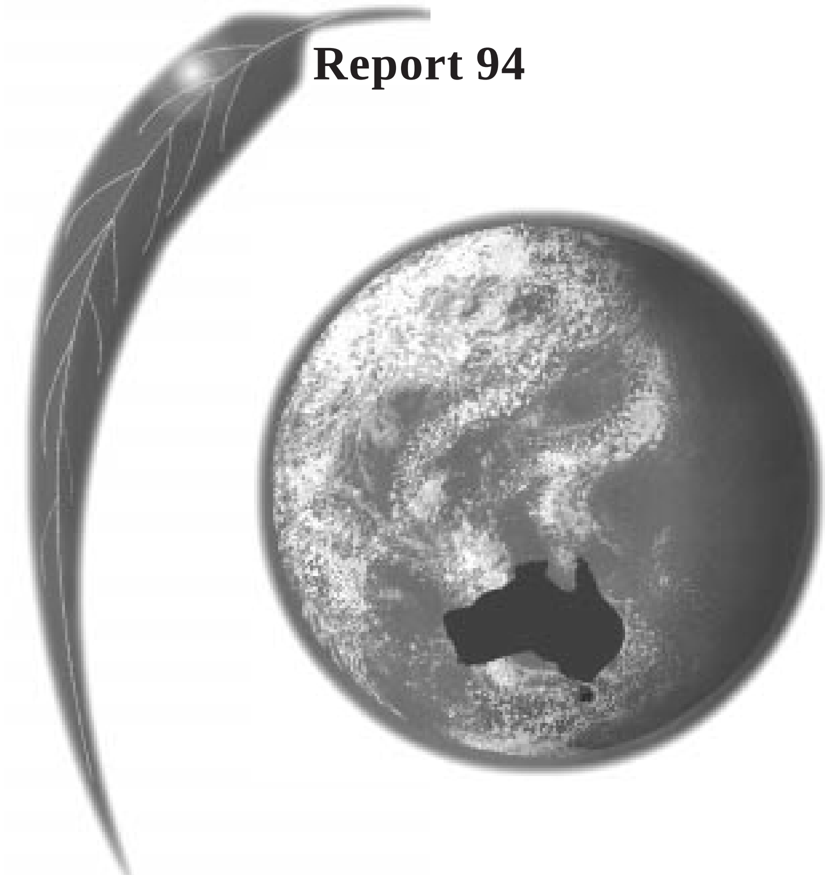
Despite popular interest in the contribution of transport to emissions of greenhouse gases, little comprehensive information has been published to date on the costs and effectiveness of the various abatement measures espoused.

BUREAU OF TRANSPORT AND COMMUNICATIONS ECONOMICS

TRANSPORT
and
GREENHOUSE

Costs and options for reducing emissions

Report 94



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FOREWORD

Motor vehicles feature prominently in everyday life.

It is therefore not surprising that cars, and occasionally trucks, are popularly identified as major sources of urban smog as well as of greenhouse emissions.

Yet popular perceptions are relatively ill-informed.

Emissions of greenhouse gases from the transport sector, for example, constitute only about 12 per cent of Australia's total output.

From dinner parties to specialist transport symposia, participants demonstrate consistently their awareness of the practical and theoretical pros and cons of various measures that could be used to reduce transport emissions. But the pattern of debate is usually predictable, because most people are by now well aware of the arguments. Lack of empirical information, however, means that debate inevitably focuses on the car alone, with the protagonists retreating to entrenched positions.

This Report injects new information into the debate. The BTCE's empirical results provide for the first time a firm basis for comparing the relative cost-effectiveness of various measures for reducing emissions of greenhouse gases in the transport sector.

A major aim was to produce a readable document, so that much of the detailed technical information on which the analysis was based has been only briefly summarised in this Report. Nevertheless substantial resources were dedicated to its production, both within and outside the BTCE. Acknowledgment of the many contributors is therefore made separately.

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July 1996

ACKNOWLEDGEMENTS

In addition to providing overall management and conceptual direction for the project, Dr Leo Dobes (Research Manager) was the principal author of chapters 1 and 2 and the glossary, and was involved particularly closely in the research and writing of chapter 14.

Due to the size and complexity of the project in its final stages over the last year or so, two teams were involved. Researchers in each contributed generously to work in the other. Brett Evill provided valuable advice and assistance to both teams on the costs of urban traffic congestion, as well as undertaking the research for chapter 18 (with the assistance of Anthony Casey) and providing particularly valuable input on the approach adopted in chapter 14.

The team led by Dr David Gargett developed fleet models for passenger and road freight vehicles and for the aviation sector. Apart from their key role in analysis, these models were used to revise the projections of basecase emissions published in BTCE Report 88, *Greenhouse Gas Emissions from Australian Transport: Long-term Projections*. Under Dr Gargett's direction, David Mitchell developed TRUCKMOD and undertook the analysis in chapters 10 and 11; David Cosgrove developed the CARMOD model and undertook the analysis in chapters 4, 5 and 17; and David Mitchell and Seu Cheng developed AVMOD and used it to produce chapter 13. Alison Bailie, Edwina Heyhoe and Anthony Casey were responsible for work utilising the ITS/BTCE model of urban household travel behaviour, including the production respectively of chapters 9, 15, and 7.

Joe Motha, principal author of chapter 14, led a team that analysed abatement options involving tree planting, vehicle labelling, improved roads, and the compulsory tuning of car engines. The following researchers contributed to this work: Marion Stefaniw and Alan Selleck (chapter 6), Catharina Williams (chapter 14), Alan Selleck (chapter 8 and the ENERGYMOD model), Edwina Heyhoe and Robin Clark (chapter 16).

Dr Chris Mitchell (CSIRO) provided invaluable assistance by redrafting some of the scientific sections of chapter 1, although responsibility for the final version rests with the BTCE.

Many others also contributed to the study. The BTCE is particularly grateful to Professor David Hensher (Institute of Transport Studies, The University of Sydney) for his enthusiasm and advice on a number of issues as well as his role as a consultant. Mick Common (Centre for Resource and Environmental Studies, ANU), Richard Kuras (Department of Foreign Affairs and Trade), Nelson English, of Nelson English Loxton & Andrews Pty Ltd, Bill Burke and David Cox (Qantas), Jack Haley (NRMA) and John Apelbaum & Associates contributed by commenting on individual chapters. Other external contributors have already been acknowledged for their specific contributions in the forewords to BTCE Working Papers 22, 23 and 24, all three of which were published earlier this year.

Over the period of three years, a number of people assisted at various times with research and presentation of the Report, including several ex-BTCE officers. The BTCE is grateful to the following officers for their various contributions: Anita Scott-Murphy, Karen Subasic, Frances DeLand, Fran O'Brien, Beryl Cuthbertson, Dr Franzi Poldy, Dr Mark Harvey, David Luck, Dr Maurice Haddad, Chris Thorpe, Ben Wilson, Chikkegowda Puttaswamy, and Tony Moleta, Paul Blair and Allan Armistead (DoTRD).

The Trace Library and BTCE Corporate Services provided information and administrative support for the project, and Maureen Wright provided invaluable editorial advice for the Report.

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ABSTRACT

Despite popular interest in the contribution of transport to emissions of greenhouse gases, little comprehensive information has been published to date on the costs and effectiveness of the various abatement measures espoused.

Using partial equilibrium analysis, the BTCE has estimated the social costs of 16 measures to reduce transport emissions from 1996 to 2015, including the costs and benefits of externalities such as urban traffic congestion and noxious emissions. Calculation of marginal costs ensures that comparisons can be made with any studies carried out for other sectors of the economy. Inclusion of all greenhouse gases, rather than just CO_2, facilitates such comparisons.

The largest potential reductions in emissions from 1996 to 2015 could be achieved by planting trees, a carbon tax on petrol, and the use of ethanol derived from wood. The social cost of implementing the measures analysed, however, varies significantly, depending on the period over which they are assessed, and the degree to which they are implemented.

Implemented at the maximum intensities assumed from 1996 to 2015, urban road user charges, a carbon tax on petrol, reduced urban public transport fares, and urban commuter parking charges are the most effective 'no regrets' measures available. Their combined implementation could reduce emissions of greenhouse gases from the Australian transport sector by 5 to 10 per cent over the period 1996 to 2015.

UNITS

The basic units used in the Report are joules (J), grams (g), metres (m) and litres (L). Standard metric prefixes are:

kilo (k)	=	10^3 (thousand)
mega (M)	=	10^6 (million)
giga (G)	=	10^9 (billion)
peta (P)	=	10^{15}

The main prefix and unit combinations found in this Report are petajoules (PJ) and gigagrams (Gg). Gigagrams are equivalent to the commonly used unit of kilotonnes (kt):

1 Gg	=	1 thousand tonnes
1000 Gg	=	1 million tonnes

In tables, 0.0 is used to denote an amount that is assumed negligible, na denotes not available and .. denotes not applicable.

THE BOTTOM LINE...

- Social cost, and effectiveness in reducing emissions, are the two major analytical perspectives adopted in this Report. Sixteen separate abatement measures are examined.
- Planting trees is the only measure that can (eventually) absorb all of the carbon dioxide emissions (about 1600 million tonnes) produced by the transport sector from 1996 to 2015. Significant reductions in all greenhouse gas emissions (in million tonnes of CO_2 equivalent) could also be achieved through imposition of carbon taxes (150), using ethanol derived from wood (144), accelerating the introduction of fuel saving technology for cars (101), and urban road user charges (90).
- If implemented to the maximum extent assumed in this Report from 1996 to 2015, the potentially most expensive measures in terms of total social cost would be scrapping of old commercial road vehicles ($19 billion), using ethanol from wood ($13 billion), tuning all cars twice a year ($13 billion), and resurfacing highways ($11 billion). Planting trees, scrapping old cars, and fuel saving and emissions technology for cars would be considerably cheaper. However, the total social cost of each measure would depend on its degree of implementation, the time period considered, and the discount rate used.
- ‘No regrets’ measures (those that would generate net social benefits because total social costs are negative) include road user charges, reduced fares on urban public transport, city-wide parking charges for commuters, shifting some intercapital freight from road to rail, a carbon tax on petrol, fuel efficiency labels on new cars, and fuel saving technology for commercial road vehicles. Combined implementation of these measures could reduce projected basecase cumulative transport emissions by 5 to 10 per cent by 2015.
- If costs to Australia are to be minimised, the choice of abatement measures should be based on comparisons of the social costs of options in all sectors of the economy, not just those in the transport sector.

REPORT FINDINGS

Although the Australian transport sector as a whole contributes only about 12 per cent to Australia's total emissions of greenhouse gases, popular prescriptions for reducing emissions tend to focus on transport, especially cars.

Most of the arguments in favour of, and against different abatement measures in the transport sector are well known. To date, however, there has been little information available on the costs of implementing them. In the absence of specific information, the protagonists have tended to retreat to preferences established on the basis of criteria other than cost-effectiveness.

The danger to the community of not basing decisions on cost-effectiveness is an unnecessary loss in welfare. Every dollar spent unnecessarily on reducing greenhouse emissions also reduces the community's ability to fund other projects such as hospitals, schools or defence.

The results in this Report permit comparison of the cost-effectiveness of 16 abatement measures. As far as the BTCE is aware, a number of them have not been analysed before in the context of greenhouse policy, either in Australia or in other countries.

The usual caveats apply to estimates of costs. Rough approximations have been used for a number of measures, particularly against a background of sparse availability of information. Assumptions and approximations have been identified specifically as far as possible, in order to ensure transparency of results. Costs are expressed in 1995–96 dollars using a discount rate of 10 per cent.

Because scientific and analytical uncertainties preclude accurate estimation of the benefits to Australia of reducing emissions of greenhouse gases, the costs of implementing specific measures cannot be compared with any benefits that might be gained from reducing emissions.

It is not the intention of the BTCE to recommend or to support the introduction of any of the measures presented in this Report. Other more cost-effective (but as yet unidentified) measures may well be available, either in the transport sector or in other sectors of the economy.

Why is the BTCE's approach different?

A major difference in the BTCE's approach is the calculation of the social costs of implementing abatement measures.

Many studies are restricted to financial costs alone; that is, monetary outlays. However, the BTCE has adopted a more comprehensive approach, in order to provide information to policy makers on the costs to the Australian community as a whole of each measure. Reliance solely on financial costs could distort policy formulation.

In particular, the BTCE has included the costs and benefits of associated externalities. For example, urban parking charges or a carbon tax are likely to have the spin-off benefit to the community of reduced traffic congestion in urban areas. Where possible, estimates of changes in consumer surplus have also been included. Because loss of consumer surplus represents inconvenience or loss of opportunity to consume goods or services (and therefore captures social or political dissatisfaction), its inclusion ensures that the true economic cost of a measure is estimated.

Calculation of marginal costs was emphasised by the BTCE, to provide policy makers with information for a range of abatement levels, not just single targets. Knowledge of marginal costs allows policy makers to decide which measures should be used, in what order, and to what extent, in a way that minimises overall costs. Information is also provided for each measure on total costs of implementation up to the years 2000, 2005, 2010 and 2015 to ensure that any fixed costs can be taken into account in comparing measures.

The nature of marginal analysis means that the BTCE's results for transport can be compared directly with marginal costs that may be calculated for any other sectors of the economy.

To permit valid comparisons with measures in other sectors, the BTCE's estimates include not only carbon dioxide (about 85 per cent of total greenhouse emissions from the transport sector), but also gases such as methane, nitrous oxide and other nitrogen oxides, and carbon monoxide.

Methane, for example, is a major emission from the agriculture sector, and is more than 20 times as potent as carbon dioxide in greenhouse terms. The BTCE's results are presented as 'carbon dioxide equivalents' to take into account the different contributions of various gases to the greenhouse effect.

Except where stated otherwise, emissions refer to those arising from vehicle operation, and do not include emissions generated during the production of the fuel used by the vehicle. Only emissions generated by vehicles operating within Australia have been included.

Selection of measures for analysis

The BTCE estimates that basecase ('business as usual') emissions from cars will grow about 10 per cent over the period 1996 to 2015, while those from trucks and light commercial vehicles will increase by about 91 per cent. Emissions from domestic aircraft movements are also expected to grow strongly, but rail and maritime emissions will remain comparatively low.

This analysis of basecase emission levels led the BTCE to focus on measures directed at reducing emissions from cars, commercial road vehicles and aircraft.

Each measure is analysed on the basis of several 'intensities', or degrees of application, to permit calculation of marginal costs (the addition to total cost of increasing intensity). For example, the carbon tax on petrol is analysed in terms of increasing tax levels. Choice of intensity levels, particularly the maximum intensity, determines both the cost and the effectiveness of each measure in terms of potential to reduce emissions **(chapter 2)**.

Measures have been analysed as if they were implemented independently of each other, in order to facilitate comparisons between them.

However, if two or more measures were to be implemented together, any interactions between them could alter their relative cost-effectiveness. For example a combination of four measures to reduce emissions from cars **(chapter 19)** results in emission reduction 13 per cent greater, and marginal costs 5 per cent lower, than when the measures are analysed as if they were independent of each other. On the other hand, implementation of some interactive measures may produce a result that is relatively dearer or less effective.

The BTCE used five models in its study. Two of the five models permitted some analysis of interactive effects.

CARMOD **(appendix VII)**, a spreadsheet model of the Australian car fleet, was developed by the BTCE to permit simulation of annual changes in fleet characteristics such as average vehicle age, average fuel consumption and total emissions. The model incorporates vehicle age-specific factors for scrapping rates, fuel consumption, annual kilometres travelled, and emission rates.

Little information has been available in the past to permit analysis of travel behaviour by individuals and households in response to changes in variables such as public transport fares, number of vehicles in a household, fuel prices, road tolls, and residential location. To fill this gap, the BTCE commissioned Professor David Hensher, Director of the Institute of Transport Studies, at The University of Sydney, to construct a model of household travel behaviour in the six major capital cities. Based on household survey data using the relatively new technique of choice modelling and sophisticated analytical techniques, the ITS/BTCE model **(appendix VI)** permits assessment of both individual and interactive abatement measures.

The overall picture

The results summarised in this section should be read in conjunction with individual chapters. While the BTCE's assumptions have been kept as realistic as possible, it is inevitable that individual readers will have their own views on the validity of various suppositions.

Tables in each chapter summarise the range of total and marginal costs and the maximum achievable cumulative reduction in greenhouse gas emissions for all measures for the years 2000, 2005, 2010 and 2015.

Overall results are illustrated in the summary figures on the following pages. Together, they present both a short-term and long-term perspective. However, discussion is mainly in terms of the year 2015 because abatement targets are usually long-term in nature.

The summary figures provide four major pieces of information:

- the maximum cumulative reduction achievable from each measure can be read from the horizontal axis directly below the end of the marginal cost curve.
- each curve indicates the additional social cost (at any given level of abatement) of reducing emissions using that measure.

- an indication of the total social cost of achieving any given level of reduction. Although normally total costs are represented by the area between a marginal cost curve and the horizontal axis, our methodology is incremental, so total costs need to be read from the tables given in individual chapters.
- a ready indication of the availability of 'no regrets' measures (those that fall below zero). 'No regrets' measures are those that reduce net greenhouse gas emissions levels, but whose total social cost is zero or negative over some specified time period.

Marginal cost curves are particularly useful in determining a least-cost set of measures at any given level of emission reduction. Their use in this manner is explained in chapter 2.

Marginal (and total costs) of an abatement measure are likely to change over time. Some measures may be cost-effective in the short term but not over a longer period, and vice versa. Commitment to short-term abatement targets may therefore result in implementation of measures that are less than optimal in the long run.

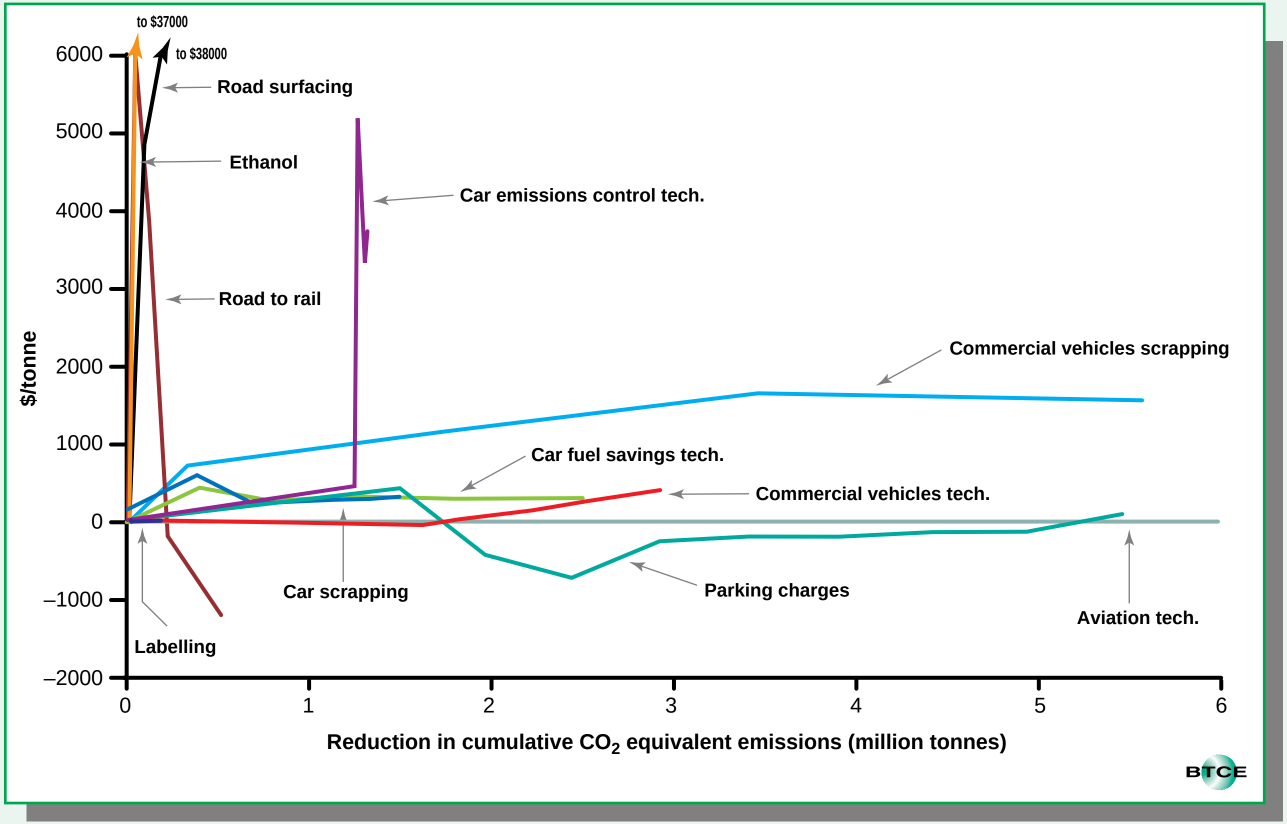
High cost measures

Scrapping older trucks and light commercial vehicles, compulsory tuning of cars twice a year, resurfacing highways, and increasing the use of ethanol derived from wood are relatively expensive measures in terms of total cost. Each involves total social costs of over $10 billion over a 20-year period at the maximum levels of implementation assumed in this Report. Of the three, increased use of ethanol would be the most effective, achieving as it does a maximum cumulative reduction of up to 144 million tonnes of CO_2 equivalent (about 8 per cent of total transport emissions) by 2015.

Tuning of cars twice a year would only result in a cumulative reduction of less than 19 million tonnes. Most of this reduction would have been achieved by the year 2010. Marginal costs of reduction would be in the order of $1000 per tonne of CO_2 equivalent over the whole period from 1996 to 2015.

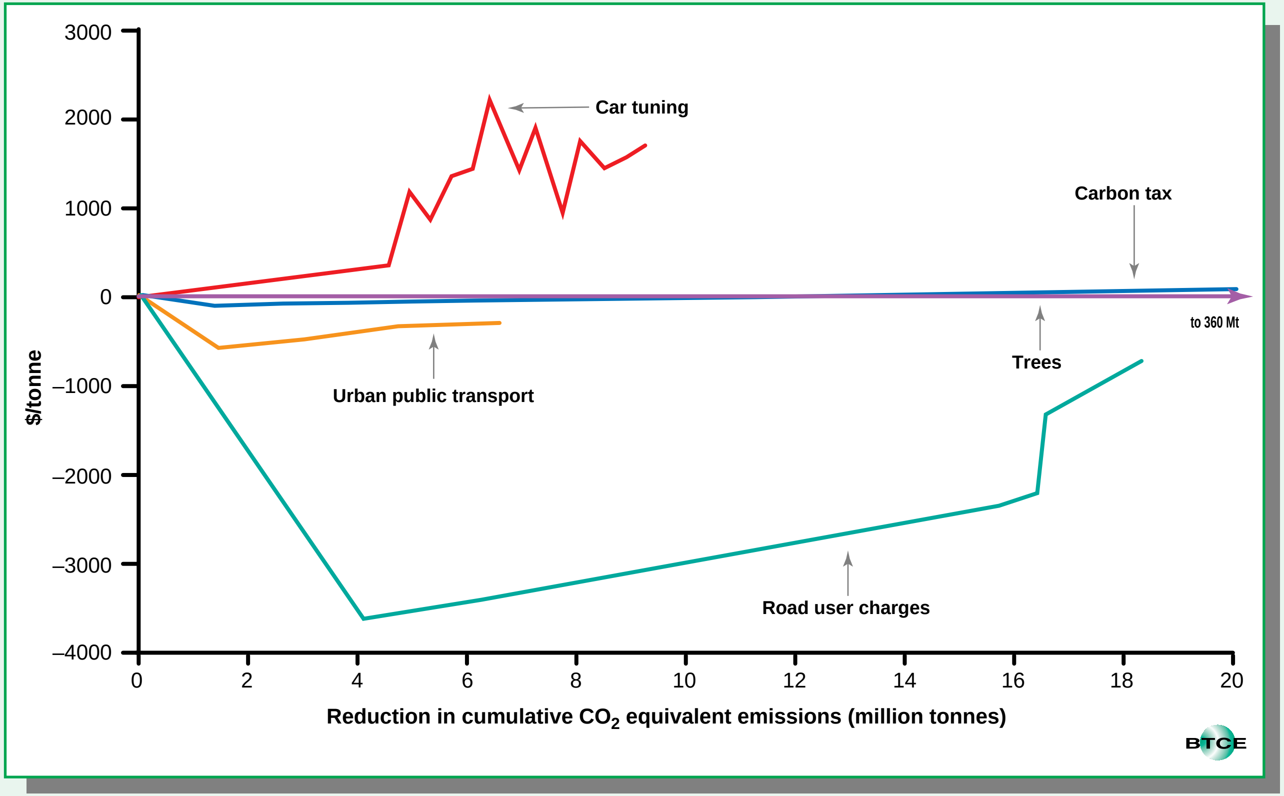
If all commercial road freight vehicles over 12 years old were scrapped automatically each year, up to 43 million tonnes in CO_2 equivalent emissions could be achieved by the year 2015 at a total social cost of almost $19 billion. Marginal costs in 2015 would be between $170 and $500 per tonne, respectively, if vehicles over 30 years of age only, or all those over 12 years old, were scrapped each year.

MARGINAL SOCIAL COST OF REDUCTIONS IN CUMULATIVE CO_2 EQUIVALENT EMISSIONS, 2000



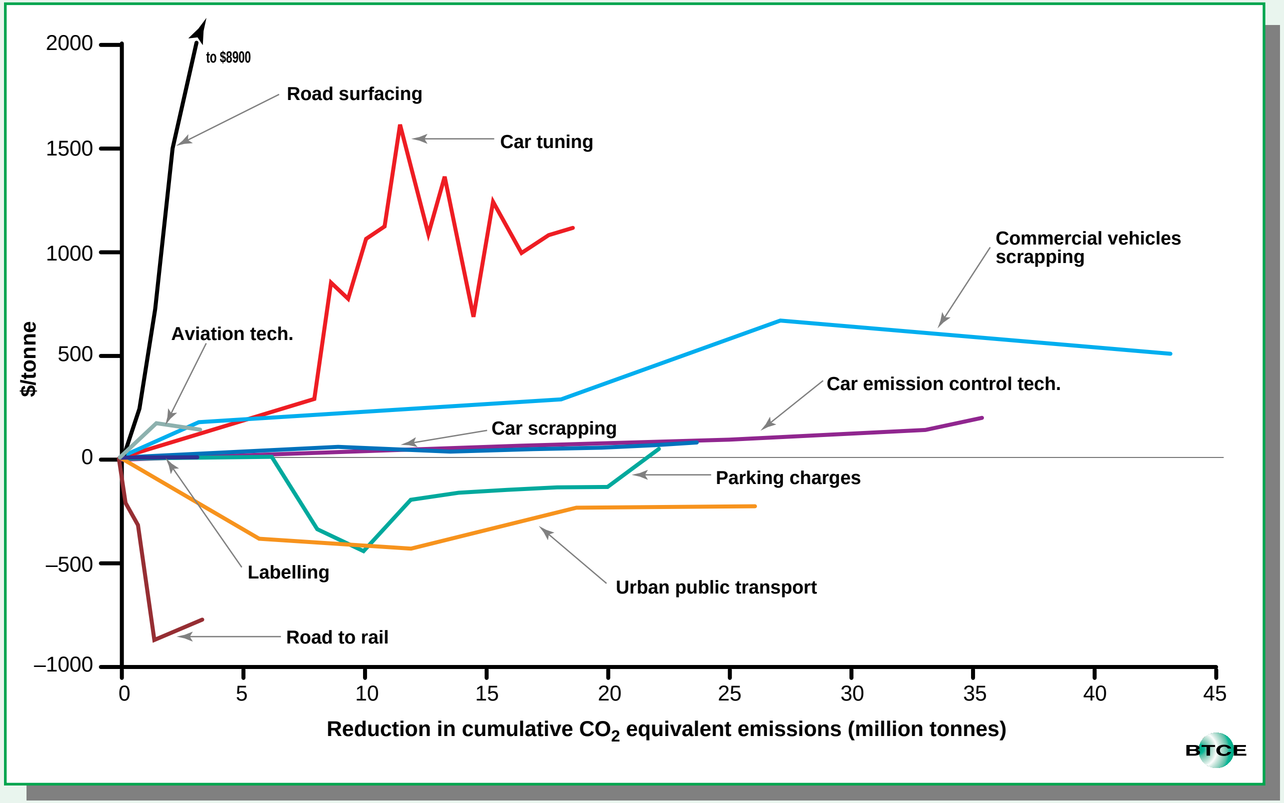
Source BTCE estimates.

MARGINAL SOCIAL COST OF REDUCTIONS IN CUMULATIVE CO_2 EQUIVALENT EMISSIONS, 2000



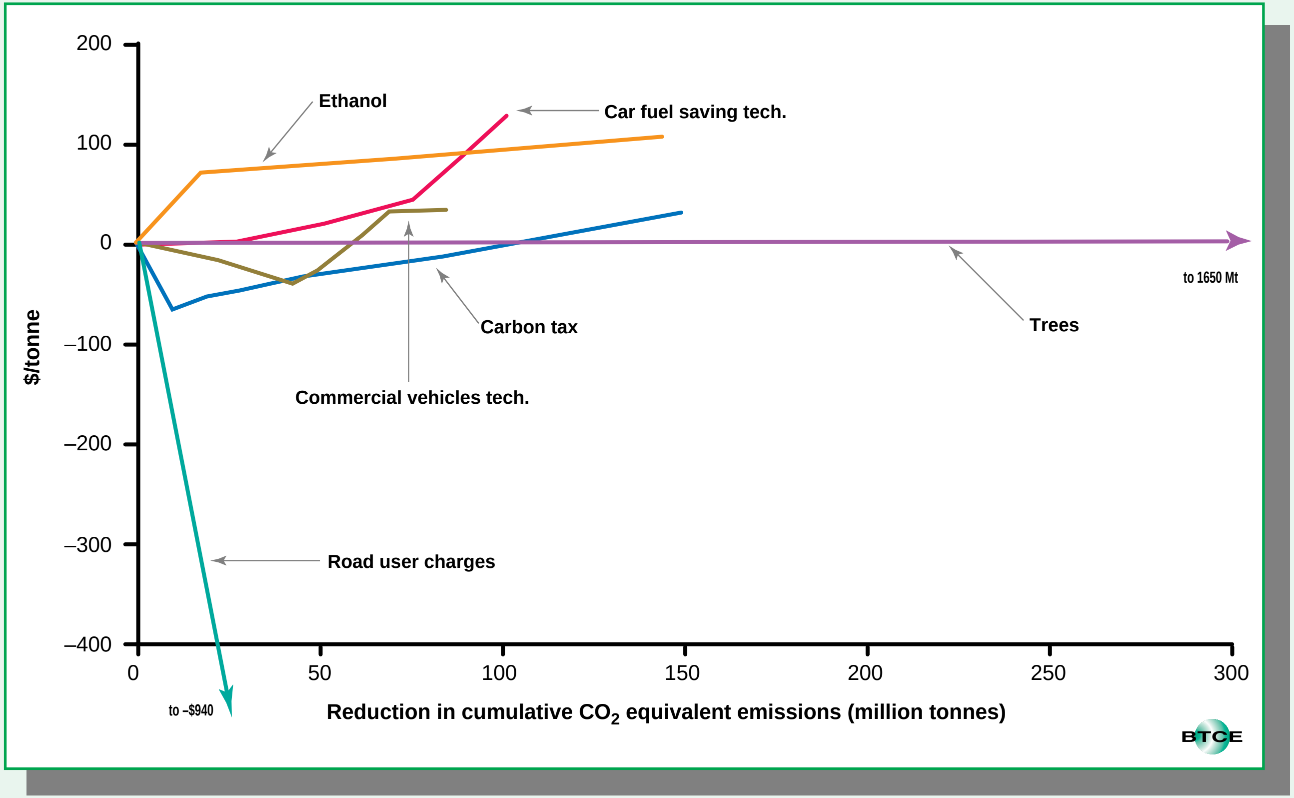
Source BTCE estimates.

MARGINAL SOCIAL COST OF REDUCTIONS IN CUMULATIVE CO_2 EQUIVALENT EMISSIONS, 2015



Source BTCE estimates.

MARGINAL SOCIAL COST OF REDUCTIONS IN CUMULATIVE CO_2 EQUIVALENT EMISSIONS, 2015



Source BTCE estimates.

Resurfacing highways to increase pavement smoothness offers a means of reducing emissions of greenhouse gases because vehicles travelling along smoother roads use less fuel.

An acceptable level of road roughness is 110 NRM. Resurfacing Australia's National Highway System to the lower roughness level of 100 NRM would reduce road transport emissions by about 0.7 million tonnes of CO_2 equivalent by 2015, at a marginal social cost of $235 per tonne. (At the maximum NRM of 60 analysed in this Report, the marginal social cost would rise to almost $9000 per tonne, but would achieve a cumulative reduction of less than 4 million tonnes of CO_2 equivalent.)

Although road resurfacing would not in itself be a particularly cost-effective greenhouse gas abatement measure, reducing the roughness of national highways would nevertheless reduce emissions of greenhouse gases. Highway improvements being undertaken for reasons other than greenhouse gas abatement can thus have a beneficial effect in terms of car emissions. Because of lower average speeds on urban roads, however, it is unlikely that the same effect would apply in congested traffic conditions in capital cities.

Low to medium cost measures

If each measure were implemented to the maximum extent assumed in this Report, planting trees, scrapping older cars, accelerating the introduction of technology to increase the fuel efficiency of car engines or to reduce emissions, and aircraft technology, would involve total social costs of between $140 million and about $9 billion by 2015.

A commercially managed tree planting program to absorb all the carbon dioxide emissions from the transport sector from 1996 would still require about $4 billion of community resources by the year 2015, even with sales of timber to offset costs. However, planting trees is the most effective measure because in the long term all CO_2 emissions from the transport sector can be absorbed without utilising more than 22 per cent of suitable land in Australia, with marginal social costs remaining below $3 per tonne of CO_2.

Because harvested wood needs to be replanted indefinitely to ensure permanent sequestration of CO_2, and because new land is required each year to absorb that year's emissions over time, the total area of land under plantation would need to expand each year. However, scope exists for joint implementation with other countries if land availability in Australia proved to be insufficient beyond the year 2015.

Car emission technology is aimed at reducing emissions of noxious gases such as carbon monoxide, oxides of nitrogen and hydrocarbons, all of which also contribute to the greenhouse effect. The marginal cost to the community of car emission technology falls in the longer term as better equipped vehicles spread through the fleet, increasing cumulative reductions in emissions from basecase levels. A maximum cumulative reduction of about 35 million tonnes of CO_2 equivalent can be achieved by 2015 at a total social cost of $3.5 billion.

Additional emission reductions from fuel saving technology for cars also become cheaper as new cars pervade the fleet. But emission reductions will be partially offset by a 'rebound' effect to the extent that savings on fuel costs by motorists encourage more car travel. Although total transport emissions can be reduced by about 5 per cent below projected basecase levels using fuel saving technology for cars, it would be more costly over the period 1996 to 2015 than planting enough trees to absorb 100 per cent of sectoral emissions.

'No regrets' measures

'No regrets' measures are those that produce net benefits to society because the social cost of implementing them is negative or zero. Individuals or groups may incur economic losses, but society as a whole will gain.

The main 'no regrets' measures in the longer term are metropolitan road user charges, reduced urban public transport fares, city-wide parking charges, labelling of new cars to inform buyers of their fuel efficiency ratings, and shifting intercapital freight from road to rail. A carbon tax on petrol and the introduction of fuel saving technology for commercial road vehicles are partial 'no regrets' measures, but costs become positive and rise after a certain degree of implementation.

Switching freight to rail becomes a 'no regrets' measure in the longer term primarily because the upgrading of more links between cities increases network economies. Even in the longer term, however, using rail for freight would reduce greenhouse gas emissions by only about 3 million tonnes of CO_2 equivalent. The limited effectiveness of the measure is due primarily to the limited scope for switching freight from road to rail.

By charging differently for travel on each road link in the capital cities, congestion is reduced to economically efficient levels. The social benefits of road user charges in capital cities would thus outweigh the costs in both the short and the long run. Imposition of economically efficient road user charges would thus be socially beneficial in addition to their effectiveness (90.5 million tonnes CO_2 equivalent by 2015) in reducing emissions of greenhouse gases.

Reduced public transport fares would increase patronage of public transport. A very large proportion of the social benefits of over $8 billion by 2015 would be due to reduced urban traffic congestion. At the maximum level of implementation assumed in chapter 15, a cumulated total of about 26 million tonnes of CO_2 equivalent emissions could be avoided.

Fuel efficiency labelling of new vehicles, using a 'star' rating system similar to that used for domestic electrical appliances, can influence buyers to choose more fuel-efficient cars. A labelling scheme would result in only a very small reduction in emissions, but if implemented from 1996 in all states and territories, this reduction could be achieved at close to negligible social cost.

A carbon tax on petrol (applied at the same time to all other fuels) would reduce emissions of greenhouse gases as motorists responded to higher prices by reducing travel, and buying more fuel-efficient cars. A tax of $2000 per tonne of carbon from the year 2000, increasing the current price of petrol to about $1.97 per litre, would reduce emissions by about 150 million tonnes with a social benefit of $874 million over the period 1996 to 2015.

Commuters would be relatively unresponsive to an increase in parking charges. A city-wide (that is, not just the central business district) charge of $12 for all-day parking would reduce greenhouse gas emissions by only about 22 million tonnes of CO_2 equivalent, about 4 per cent of total urban transport emissions. However, reduced congestion, accidents and levels of noxious emissions would result in a net benefit to society of almost $3 billion over the period 1996 to 2015.

A large proportion of the social benefits (negative social costs) gained from a carbon tax, commuter parking charges, and urban road charges, are due to reductions in traffic congestion. The benefit of reduced congestion is measured in terms of the value of travel time 'saved' in faster flowing traffic. However, the value ascribed to the time saved involves a number of important conceptual issues that are addressed in appendix XIII.

What can be achieved using 'no regrets' measures?

Assuming that Australian governments were to implement 'no regrets' measures in the transport sector, it is arguable that the first measure that should be implemented is road user charges.

Imposition of road user charges on all road links in capital cities would ensure that traffic levels were economically efficient. Implementation of further abatement measures would therefore begin from an optimal situation.

Introduction of a fuel efficiency labelling scheme and the upgrading of intercapital rail links could be a complementary measure because there would be little interaction with road user charges. The total reduction in emissions from 1996 to 2015 would be over 95 million tonnes of CO_2 equivalent, and the benefit to society in the order of $100 billion.

A carbon tax, reduced public transport fares, and city-wide parking charges would tend to have similar effects in reducing traffic levels, but, taken together, their effect would be less than the sum of their individual effects if implemented alone. Their effect, alone or together, would also be reduced if they followed the imposition of road user charges.

Nevertheless, if all five 'no regrets' measures were introduced simultaneously, it is likely that a cumulative reduction in emissions of between about 100 and 200 million tonnes of CO_2 equivalent could be achieved. This represents between 5 and 10 per cent of total transport sector emissions over the period 1996 to 2015. Because the social benefits would be substantial, the measures would be worth implementing in their own right, although social returns from measures implemented in other areas of the economy could be higher.

Equity issues

Consideration of equity issues is a complex matter, with few simple answers.

At the simplest level, specific measures can be assessed in terms of their effect on the disposable incomes of individuals. However, transport resources are often pooled within households because their members may lend each other vehicles, or drive others to their destination. Where this is the case, equity considerations would be better assessed by reference to total household income, rather than on an individual basis.

On the other hand, the consumption of transport services is comparable to consumption of other services, such as use of electricity. Given that households and individuals already pay income tax at progressive levels, it is at least arguable that income should not be a criterion in assessing alternative measures.

In the case of measures that raise revenue, such as road user charges, the use to which the revenue is put (for example, increased expenditure on hospitals) is an essential consideration in assessing the impact of a measure on different groups in the community. Recycling of revenues collected from a group as large as motorists, for example, means that a large proportion of those revenues is ultimately returned to the same group and at least partially nullifies any initial loss in income.

Promotion of some forms of transport may be less equitable to particular members of the community. The aged, women and the disabled, for example, may value travel by car more highly because of their individual lack of mobility, or because of concerns about personal security if they are required to use public transport.

The question of accessibility is important to those living in areas where there is no effective choice of transport mode. Even if residents of outer urban areas, for example, have access to public transport it may be of little use in travelling across the city within reasonable times for reaching work, or visiting friends.

Geography is also important. Measures such as urban road user charges may be cost-effective from the perspective of society as a whole, but their incidence would fall only on urban residents. Rural residents, on the other hand may feel relatively disadvantaged by a measure such as a carbon tax on petrol because of the greater distances that they need to travel.

Because each of the measures analysed in this Report has different equity implications, there is no single, common thread or conclusion that can be drawn from the issues considered. The national scope of the analysis in this Report means that individual chapters necessarily deal with equity issues from a broad, national perspective.

Full consideration of equity issues would need to be cast in terms of the specific circumstances of those affected, on a case by case basis for each measure that might be implemented.

WHY IS THIS BTCE REPORT DIFFERENT?

The BTCE Greenhouse Study is based on a number of key features that distinguish it significantly from other studies:

- Cost functions have been developed for varying degrees of application (intensity), rather than estimating costs just for one 'target' level of emission reduction. The BTCE approach therefore provides policy makers with a choice from a range of abatement levels.
- All greenhouse emissions, not just carbon dioxide, are included. Estimates of costs in terms of 'CO_2 equivalents' permit more accurate comparisons with other sectors of the economy such as agriculture.
- Policy decisions based on analyses that provide only financial costs of abatement measures are likely to underestimate true social costs. The BTCE has calculated full economic costs, rather than just financial costs. Loss of consumer surplus, which can be thought of as loss of opportunity to consume goods or services or as increased inconvenience (and therefore social or political dissatisfaction), has been included for most measures.
- Because changes in congestion and health effects from noxious emissions have been taken into account, the BTCE's estimates reflect more accurately the costs and benefits to the community of specific measures.
- To minimise the social cost to Australia, selection of abatement measures requires information on implementation costs in all sectors of the economy. (Transport produces only 12 per cent of all greenhouse emissions.) The BTCE's pragmatic approach provides an effective and flexible methodology that can be applied to other sectors.

CHAPTER 1 INTRODUCTION—PUSHING THE FRONTIER

There is a plethora of literature, both technical and popular, about the transport sector and greenhouse gas emissions.

What has been missing until now is factual information about the costs of reducing greenhouse gas emissions, particularly in the Australian transport sector.

The debate in Australia has reached the stage where most discussions have become predictable. The theoretical and practical pros and cons of the various measures that could be used to reduce transport emissions are generally well known, even among non-specialists. As a consequence, discussion has become increasingly circular and repetitive, and proponents of particular views have tended to retreat to familiar, fixed positions.

The primary objective of this Report is to provide information that will provide a firmer basis for public debate, as well as establishing a firm basis for the development and formulation of policies by governments.

Some of the results obtained have surprised even the researchers involved.

The BTCE Greenhouse Study—innovations in approach

Many studies in recent years have focused simply on estimating the costs of implementing specific greenhouse abatement targets.

The BTCE approach is based on estimating costs for a range of abatement levels, not just single targets.

It was considered from the outset that a more comprehensive approach would provide policy makers with a better basis for identifying policies that would minimise costs borne by the Australian community. Better information on costs was also seen as a means of assisting development of an Australian position in international negotiations.

Calculation of *marginal costs* was emphasised by the BTCE to provide information to policy makers on the relative cost-effectiveness of different options in the transport sector. However, the nature of marginal analysis means that the BTCE results can be compared directly with any marginal costs that may in future be estimated for other sectors of the economy. Comparisons are required to ensure that any measures selected will minimise the overall cost to the Australian community **(chapter 2)**.

Economic costs, rather than just financial costs, have been presented to ensure that the full economic cost of each abatement measure is identified. For most measures, any losses in consumer and producer surplus have been included. Loss in consumer surplus can be thought of as loss of opportunity to consume goods or services, or as increased inconvenience. To the extent that loss of consumer surplus reflects dissatisfaction with specific abatement measures, it constitutes an indirect measure of social or political 'pain' involved in their implementation.

Valid comparisons of abatement measures in different sectors of the economy also require a common unit of measurement. Carbon dioxide, which accounts for about 85 per cent of all transport emissions, is assigned a global warming potential (GWP) of 1. But other greenhouse gases have different GWPs **(appendix IV)**. For example, methane, which is emitted in large proportions by agriculture, is more than 20 times as potent as carbon dioxide in terms of global warming potential. The BTCE analysis was therefore based on CO_2 equivalent emissions.

As is well known, some greenhouse abatement measures directed at transport, such as urban parking charges or carbon taxes, are likely to have spin-off benefits in reduced urban congestion. Few studies have been able to quantify these effects accurately and include them in their estimates of the social costs of reducing emissions. Analytical capabilities developed recently by the BTCE in the area of congestion costs and road user charges meant that the results in this Report include appropriate adjustments to estimates of social costs.

Together with the innovative nature of the modelling used, the combined effect of the above analytical innovations represents a significant pushing outwards of the 'frontier' of knowledge of the costs of abatement measures in the transport sector.

SOME COMMONLY USED TERMS

A number of terms have been used throughout this Report. The terms below and related concepts are defined in the Glossary.

Financial cost Expressed or measured in terms of actual money outlays or expenditure. An example is the amount paid for petrol by a motorist.

Economic cost Measured in terms of the most valuable alternative or opportunity forgone in order to achieve or acquire something. Equal to financial cost if and only if the prices in which expenditure is calculated correctly reflect the value of a resource in alternative uses. An example of an economic cost is the current market value of a block of land, rather than the (historic) financial outlay made to acquire it.

Social cost Where economic costs need to be calculated on a national level, as in this Report, they are normally expressed as costs to the community as a whole. They are determined by aggregating the (private) economic costs incurred by individuals as well as (public) costs or benefits of externalities. Taxes (such as fuel excise) and subsidies are not included because they represent transfer payments from one section of the community to another.

Marginal cost (of reducing greenhouse gas emissions) The extra social cost incurred when the level of greenhouse emissions is reduced or increased by one (technically infinitesimal) unit. Marginal costs in this Report are based on differences in intensity (degree of application) of an abatement measure cumulated from 1996 to a snapshot year, as illustrated in **figure 2.6**.

Consumer surplus The difference between the amount a consumer is willing to pay for a good or service (rather than go without it), and the amount actually paid. Usually aggregated over all consumers.

Producer surplus The excess of total receipts by a producer (a firm or an individual) supplying a good or a service over the total avoidable cost of supplying that level of good or service, excluding the cost of capital.

Global warming potential (GWP) An index used to compare the relative potency of different greenhouse gases, defined in terms of cumulative radiative forcing over a specified time period. See also **appendix IV**.

Policy implications of BTCE results

Due care needs to be exercised in drawing policy conclusions from the results in this Report.

The usual caveats apply to estimates of costs. Rough approximations have necessarily been used for a number of measures, particularly against a background of sparse availability of information on costs. Clearly, results can only be as good as the quality of the data used.

Despite the range of policy instruments evaluated, it is conceivable that other, more cost-effective measures could be applied in the transport sector. The scope for technological and behavioural change, in particular, should not be underestimated over a projection period as long as 20 years.

Alternatives such as adaptation to climate change through measures such as genetic engineering of crops or building sea walls also need to be considered in conjunction with abatement measures, in order to ensure an overall least-cost policy outcome.

There is some risk that information presented in this Report may attract premature interest on the part of policy makers because comparable information for other sectors is not readily available. But introduction of greenhouse abatement measures in the transport sector alone is likely to be more costly to Australia than implementation of a least-cost range of measures based on available options in all sectors of economic activity.

Selection of options other than a least-cost set would result in an unnecessary reduction in the community's welfare because of the greater economic costs involved.

What is the greenhouse effect?

The greenhouse effect and its implications for climate change are summarised in the box opposite.

A general, non-technical explanation of the greenhouse effect is presented in NGAC (1992). Flannery (1994) provides an interesting Australian paleontological and botanical perspective. Implications of climate change for Australian droughts and floods are reported by Whetton et al. (1993) on the basis of a general circulation model. Industry Commission (1991) provides a comprehensive survey of major climatological and socioeconomic issues, including a useful bibliography.

The natural greenhouse effect maintains the earth's surface temperature at around 33°C warmer than it would otherwise be, a level suitable for sustaining life. At issue is the extent of the anthropogenic (human-induced) contribution to climate change.

It is principally the increased use by humans of fossil fuels such as coal and oil, as well as changes in land use since the pre-industrial era (from about 1750), that has increased atmospheric concentrations of greenhouse gases substantially. To the extent that emissions are re-absorbed by trees (through photosynthesis), non-fossil fuels such as wood do not add to the atmospheric stock of carbon dioxide.

WHAT DETERMINES CLIMATE CHANGE?

The earth absorbs radiation from the sun, mainly at the surface. This energy is redistributed by atmospheric and oceanic circulation and radiated to space at longer 'terrestrial' or 'infrared' wavelengths. On average, for the earth as a whole, the incoming solar energy is balanced by outgoing terrestrial radiation.

Any factor which alters the radiation received from the sun or lost to space, or which alters the redistribution of energy within the atmosphere, and between the atmosphere, land and ocean, can affect climate. A change in the energy available to the global earth/atmosphere system is termed radiative forcing.

The sun's output of energy varies by small amounts (0.1 per cent) over an 11 -year cycle, and variations over longer periods occur. On time scales of tens to thousands of years, slow variations in the earth's orbit have led to changes in the seasonal and latitudinal distribution of solar radiation; these changes have played an important part in the variations of climate in the distant past, such as the glacial cycles.

Any human-induced changes in climate will be superimposed on a background of natural climatic variations which occur over a whole range of space and time scales.

The enhanced greenhouse effect reinforces an effect which has operated in the earth's atmosphere for billions of years due to the naturally occurring greenhouse gases: water vapour, carbon dioxide, ozone, methane and nitrous oxide. Increases in concentrations of greenhouse gases reduce the efficiency with which the earth radiates energy back into space because more of the outgoing terrestrial radiation from the surface is absorbed by the atmosphere. This absorption results in positive radiative forcing which tends to warm the lower atmosphere (the troposphere). The amount of warming depends on the increase in concentration of each greenhouse gas, the radiative properties of the gases involved, and the concentrations of other greenhouse gases already present in the atmosphere.

Anthropogenic aerosols (small particles) in the troposphere, derived mainly from the emission of sulphur dioxide from fossil fuel burning, and from other sources such as biomass burning, can absorb and reflect solar radiation. In addition, changes in aerosol concentrations can alter cloud amount and cloud reflectivity. In most cases tropospheric aerosols tend to produce a negative radiative forcing, and result in cooler climate. They have a much shorter lifetime (days to weeks) than most greenhouse gases (decades to centuries) so their concentrations respond much more quickly to changes in emissions.

Volcanic activity can inject into the stratosphere large amounts of sulphur-containing gases (primarily sulphur dioxide) which are transformed into aerosols. This can produce a large, but transitory (a few years), negative radiative forcing, tending to cool the earth's surface and lower atmosphere over periods of a few years.

Climate variations can also occur in the absence of a change in external forcing, as a result of complex interactions between components of the climate system such as the atmosphere and ocean. The El Niño–Southern Oscillation (ENSO) phenomenon is an example of such natural 'internal' variability. To distinguish anthropogenic climate changes from natural variations, it is necessary to identify the anthropogenic 'signal' against the background 'noise' of natural climate variability.
(Adapted from IPCC 1996, p. 14)

Greenhouse emissions from the Australian transport sector

In terms of global emissions of greenhouse gases, the USA and the former Soviet Union were the world's largest emitters in 1991, being responsible for about 19 and 13 per cent respectively. Australia produced just over 1 per cent of the world's emissions, being ranked in about 16th place (WRI 1994, p. 201, reproduced in BTCE 1995c, p. 9).

Despite its relatively low ranking in global output, Australia has one of the highest per capita levels of greenhouse emissions (table 1.1). Both overall energy emissions and those from the transport sector are above the OECD average.

The Australian transport sector generates both direct (radiatively active) and indirect greenhouse gases. The main direct greenhouse emissions apart from water vapour are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs). Indirect greenhouse gases such as carbon monoxide (CO), oxides of nitrogen (NO_x) other than nitrous oxide, and non-methane volatile organic compounds (NMVOCs) do not have a strong radiative effect themselves, but influence atmospheric concentrations of the direct greenhouse gases. BTCE (1995c, appendix I) summarises the properties and atmospheric effects of greenhouse gases emitted by transport vehicles.

In comparisons limited to energy usage, transport's contribution is about 25 per cent of Australian greenhouse emissions. Because it is not always made clear when this figure is quoted that it excludes non-energy sources such as methane emissions from agriculture or coal mines, it is often misinterpreted as meaning that transport is responsible for a quarter of Australia's greenhouse emissions.

In fact, the transport sector is the source of only about 12 per cent of total Australian greenhouse emissions (table 1.2). (Even this figure overstates the contribution of transport to nationally attributable emissions because it includes emissions from ships and aircraft operating outside Australia.) Within Australia, transport contributes only of the order of 15 per cent of carbon dioxide, the major greenhouse output from the transport sector.

Cars are often depicted as a major villain in greenhouse terms, possibly because of their prominence in daily life.

It is therefore valid to ask whether transport would have contributed more or less to domestic greenhouse emissions in the absence of the internal combustion engine. Animals that were used for transport 100 years ago produced methane and nitrous oxide, both of which are far more potent greenhouse gases than carbon dioxide, the major emission

TABLE 1.1 CO_2 EMISSIONS[a] FOR SELECTED COUNTRIES, 1990

Country	Population 1990 *(millions)*	Energy use emissions *(million tonnes)*	Energy use emissions per capita *(tonnes)*	Transport emissions *(million tonnes)*	Transport emissions per capita *(tonnes)*	Contribution of transport to energy use emissions *(per cent)*
Australia	17.1	288.4	16.88	67.0	3.87	23.2
Belgium	10.0	122.1	12.26	36.3	3.64	29.7
Bulgaria	8.8	81.5	9.24	11.8	1.34	14.5
Canada	26.5	452.7	17.07	144.9	5.46	32.0
Denmark	5.1	55.5	10.80	15	2.92	27.0
Finland	5.0	60.6	12.14	15	3.01	24.8
France	56.4	350.5	6.21	116.7	2.07	33.3
Hungary	10.6	75.2	7.13	10.4	0.99	13.8
India	850	563	0.66	66	0.08	11.7
Indonesia	178	118.2	0.66	30.7	0.17	26.0
Italy	57.7	371.8	6.45	101.6	1.76	27.3
Japan	124	1 074.7	8.67	214	1.73	19.9
New Zealand	3.4	26.2	7.68	10.3	3.02	39.3
Nigeria	115.5	71.6	0.62	6.2	0.05	8.7
Philippines	61.5	38.4	0.62	13.5	0.22	35.2
Poland	38.2	473.5	12.40	34.6	0.91	7.3
Sri Lanka	17.0	3.5	0.21	2.1	0.12	60.0
Sweden	8.6	56.3	6.58	24.3	2.84	43.2
Switzerland	6.7	45.9	6.84	16.9	2.52	36.8
Turkey	56.1	182.5	3.25	21.6	0.39	11.8
United Kingdom	57.4	564	9.83	120.7	2.10	21.4
United States	250	5224	20.90	1 527	6.11	29.2
OECD	839	10 300	12.12	2 800	3.34	27.2
World	5 292	22 700	4.29	4 370	0.83	19.3

a. CO_2 only, as distinct from CO_2 equivalent emissions.

Notes 1. Emissions include those due to bunker fuel consumed by international transport.

2. Many of the estimates in this table are based on limited or preliminary data and are therefore very approximate.

Sources World Bank 1992; ECMT 1994, pp. 4–12; BTCE estimates based on OECD/IEA 1991 and OECD 1994.

TABLE 1.2 AUSTRALIAN GREENHOUSE GAS EMISSIONS, 1990

	Global warming potential	*Contribution to Australian CO_2 equivalent emissions*	*Australian human-sourced emissions (gigagrams of gas)*		*Contribution of transport vehicles to Australian emissions (per cent)*[c]	
Gas[a]	*(GWP)*	*(per cent)*	*Energy use*	*Total*[b]	*Energy use*	*Total*[b]
Direct						
Carbon dioxide	1	58.6	288 353	426 088	23.2	15.7
Methane	24.5	21.0	1 054	6 244	2.1	0.4
Nitrous oxide	320	2.7	3.7	60.3	61.4	3.8
CFCs	8 500[d]	9.5[e]	..	13	..	5[f]
Indirect[g]						
Carbon monoxide	1	3.6	4 470	26 082	85.4	14.6
Nitrogen oxides	8	2.1	1 276	1 949	39.0	25.5
Non-methane volatile organic compounds	8	2.5	628	2 238	82.9	23.3
Total CO_2 equivalent	..	100	335 100	727 000[e]	25.4	11.7

.. Not applicable

a. The major greenhouse gas is water vapour. However, water vapour is not normally considered in greenhouse gas inventories because human output is negligible when compared to the day-to-day precipitation cycle.

b. Includes all man-made sources and sinks for emissions from energy use, industrial processes, agriculture, land use change and forestry, and waste disposal.

c. Includes emissions from military transport and emissions due to Australian bunker fuel consumption by international transport.

d. GWPs (100-year time horizon) for various CFCs range between 4000 and 11 700. The value given here is for CFC-12, the main gas used in vehicle air-conditioners.

e. The net warming effect of CFCs is uncertain, since CFC-induced depletion of stratospheric ozone results in negative (global average) radiative forcing. Since the late 1970s, the negative indirect effect has been of a similar magnitude to the positive direct effect (IPCC 1994, p. 5). Estimated total CO_2 equivalent emissions less CFCs for Australia in 1990 are 658 000 Gg, of which CO_2 accounts for 65 per cent.

f. Emissions during vehicle operation would account for only around 5 per cent of national CFC output. The share is considerably higher (up to 18 per cent) when allowance is made for CFC release due to vehicle servicing, accidents, manufacture and disposal.

g. Includes warming effects due to the production of tropospheric ozone. Does not include indirect effects due to carbon emitted as CH_4, CO or NMVOCs (which are eventually converted to CO_2 in the atmosphere) since CO_2 estimates are made on the assumption of total conversion of fuel carbon content to CO_2. The GWP for methane includes both direct and indirect effects.

Notes 1. The figures provided in the table refer to ‘end-use’ emission estimates: that is, for transport, the emissions resulting solely from vehicle operation.

2. Gigagrams equals 109 grams, sometimes called a kilotonne.

Sources NGGIC 1994c, pp. 12–13; DME 1990, pp. 22–23; IPCC 1990, pp. 11–13, 1992, pp. 19–2, 1994, p. 28; Cosgrove 1992, p. 7; BTCE estimates.

today. A study by Dobes (1995) concluded that reliance on fossil fuels by the transport sector is no worse in terms of greenhouse emissions and possibly better than the pre-motorised era, after taking into account growth in Australia's population and GDP.

Are humans really causing global warming? —The scientific debate

No attempt has been made in this Report to assess the scientific evidence for the anthropogenic greenhouse effect. However, there is considerable uncertainty about the magnitude and timing of any effect.

A former Chief of the Division of Atmospheric Research, Commonwealth Scientific and Industrial Research Organisation, Dr Brian Tucker (1994, 1996), argues that greenhouse policy and national abatement targets have moved beyond the point that can be supported by scientific knowledge. According to Tucker (1996, p. 9):

> Only two climatic predictions can be hazarded with any degree of confidence: some degree of global warming (but prediction of the magnitude of this depends on a correct treatment of important processes represented in the models); and with somewhat less confidence, sea level rises due to thermal expansion of sea water (but these will be modulated by the effect of polar ice-cap changes—increases or decreases, we don't yet know which), and vertical land movements of similar magnitude due to other processes. There is scientific consensus on little else.

In its latest report, the Intergovernmental Panel on Climate Change (IPCC) notes that global mean surface air temperature has increased by between about 0.3°C and 0.6°C since the late nineteenth century, but:

> There are inadequate data to determine whether consistent global changes in climate variability or weather extremes have occurred over the 20th century. On regional scales there is clear evidence of changes in some extremes and climate variability indicators (e.g., fewer frosts in several widespread areas; an increase in the proportion of rainfall from extreme events over the contiguous states of the USA). Some of these changes have been toward greater variability; some have been toward lower variability (IPCC 1996, p. 4).

The IPCC (1996, p. 10) distinguishes between the *detection* and *attribution* of anthropogenic climate change. Detection is described in terms of the use of statistics to test whether natural climatic variability can, at a given level of probability, account for the historic changes in climate that have been observed. Attribution is the process of identifying a cause for observed changes, including testing competing hypotheses.

IPCC (1996, p. 11) concludes that 'the balance of evidence suggests a discernible human influence on global climate'. This statement is not intended to refer solely to 'human influence' in terms of greenhouse gases, but includes the effects of anthropogenic aerosols which produce a cooling at the earth's surface, and depletion of ozone which reduces warming near the tropopause (the upper boundary of the troposphere).

The IPCC (1996, pp. 438–439) further points out that while some scientists would argue that confident detection and attribution of a significant anthropogenic climate change has already occurred, others maintain that we do not know when we will know for certain. In any case, few scientists would be willing to argue that all or part of observed climate change can be attributed unambiguously to humans, or that change is likely in the next few years.

Interpretation of the historic record has produced some disagreement. Emsley (1996) and others have pointed to the reliance on measurement of land temperatures, despite the fact that two-thirds of the earth's surface is covered by water. Considerable scientific effort has been expended to account for biases due to factors such as the warmth of cities (so-called urban heat islands), and the geographic and temporal distribution of measuring sites.

Satellite observations of terrestrial temperatures made for the last 16 years indicate cooling in parts of the atmosphere above the earth's surface. The reason for the discrepancy between satellite and ground-based observations is not well understood. Climatologists are actively researching the reasons for the differences between the two sets of temperature records.

Even where there is agreement over what has been observed, the IPCC finding that part of the observed change is likely to be due to human influences has been a point of considerable debate. The scientific discussion has been complex, revolving around the ability of climate models to reproduce the climate observed over this century, and the extent to which incorporation of the cooling effect of aerosols in models improves the 'fit' between observations and model simulations.

One commentator, Michaels (1996), argues that about 0.25°C of the observed 0.5°C temperature increase over the past century is due to greenhouse gases produced by human activity. He attributes the remainder of the warming to variability in solar radiation. Based on the warming experienced to date, and the causative factors he uses to account for it, Michaels argues that future warming will be small.

Unlike Michaels' approach, most scientific predictions of future warming are based on coupled oceanic and atmospheric models that are used to simulate future climatic conditions in response to assumed changes in greenhouse gases. Such simulations are based on an annual assumed increase in carbon dioxide concentrations of 1 per cent, or changes in atmospheric concentrations derived from some 'business as usual' scenario of emissions. A commonly used standard for comparing the future with present-day climate is a doubling of atmospheric carbon dioxide concentrations, compared to pre-industrial levels.

The IPCC models climate change on the basis of scenarios of different global levels of greenhouse gas emissions. For the mid-range IPCC emission scenario, and using a 'best estimate' for the response of climate to greenhouse emissions, climate models simulate a global mean surface temperature increase in 2100 relative to 1990 of about 2°C. This estimate is about one-third lower than the IPCC's 'best estimate' of 3.2°C in 1990.

The reasons for the IPCC's revision of its predictions are three-fold. First, the cooling effects of aerosols are taken into account in the current assessment whereas they were not previously. Second, the ability of plants to respond to increased carbon dioxide in the atmosphere is now included in the calculations. This results in less carbon dioxide predicted in the atmosphere at the end of the next century. Third, anthropogenic emissions of carbon dioxide are assumed to be slightly lower than they were in previous work.

As in the case of modelling of complex systems in most fields of knowledge, there is disagreement over the veracity of climate model results, and, more importantly, the extent to which the results from climate models should be used as inputs to decision making. In the first instance, climate models are acknowledged as being imperfect. Second, although climate simulations can be tested against the climate system observed during the past 100 years, simulations of future climate decades or centuries from now cannot be tested—in the conventional sense—against observations.

A detailed, useful review of the literature and arguments for and against climate modelling and use of historical data is presented in Pittock (1993), who emphasises the need for scenario analysis in the face of scientific uncertainty.

International negotiations on climate change

Concern about the potential effects of climate change has prompted a number of international conferences in recent years. One of the most influential has been *The Changing Atmosphere: Implications for Global Security* conference, held in Toronto in June 1988. The conference urged all governments to adopt action plans aimed at reducing annual CO_2 emissions to 20 per cent below 1988 levels by the year 2005. The outcome has since become known as the 'Toronto target'.

The principal international body investigating greenhouse issues, the Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP). Its three Working Groups (Science, Impacts, and Response Strategies) have been tasked with assessing the scientific basis of global climate change, evaluating the environmental and socioeconomic impacts, and formulating possible response strategies. The IPCC does not make policy recommendations.

International negotiations commenced in January 1991 for a Framework Convention on Climate Change (FCCC). The text of the Convention adopted at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in June 1992 was signed by more than 150 countries, including Australia. In December 1992 Australia ratified the Convention, which entered into force on 21 March 1994 following ratification by the requisite 50 countries.

The FCCC does not contain a binding target, but calls on developed countries and others identified in Annex 1 to the Convention to adopt policies and measures with the aim of returning their greenhouse gas emissions to 1990 levels by the end of the present decade (UNEP/WMO 1994). Participating countries are required to maintain inventories of greenhouse gas emissions, to cooperate in international research and to develop cooperatively strategies for emission reduction. However, commitments by the Parties to the Convention are qualified by their 'taking into account their … specific national and regional development priorities, objectives and circumstances'.

The first 'Conference of the Parties' (COP1) to the Convention took place in Berlin in March–April 1995, and mandated negotiation of a new set of post-2000 (up to 2020) commitments for Annex I Parties but no new commitments for developing countries. Australia argued that, in the light of rapidly increasing emissions from developing countries, there was a need for greater developing country involvement in emission reduction efforts in order to ensure an effective global response. This position did not, however, receive much support.

A second Conference of the Parties (COP2), held in Geneva from 8 to 19 July 1996, resulted in a Ministerial Declaration calling for accelerated negotiations on the text of a new legal instrument, to be adopted at COP3 in Kyoto, Japan, in December 1997. While Australia endorsed the Ministerial declaration, it did not agree to the commitment that the outcome of the Berlin mandate negotiations would include legally binding targets, without the nature and content of the commitments being clear.

A major unresolved issue in international negotiations that is particularly relevant to Australia is the attribution of bunker fuel used by ships and aircraft on international routes. To ensure that all fuel use is accounted for, the IPCC recommends that countries should 'record separately [from domestic usage] the quantities of fuel uplifted' by international ships and aircraft (IPCC/OECD 1994, p. 1.11).

Measures analysed in the BTCE Greenhouse Study were therefore limited to those directed at reducing domestic emissions. Basecase projections in appendix III are presented separately for domestic and international transport.

Australia's response to the international debate

In October 1990, the Australian Government adopted an Interim Planning Target for greenhouse gases based on the Toronto target. The aim of the Interim Planning Target is:

> to stabilise greenhouse gas emissions (not controlled by the Montreal Protocol on Substances that Deplete the Ozone Layer) based on 1988 levels, by the year 2000 and to reduce these emissions by 20 per cent by the year 2005... subject to Australia not implementing response measures that would have net adverse economic impacts nationally or on Australian trade competitiveness, in the absence of similar action by major greenhouse producing countries (Commonwealth of Australia 1992).

Following signature of the FCCC by the Commonwealth Government, all Australian governments endorsed a National Greenhouse Response Strategy (NGRS) at the 7 December 1992 meeting of the Council of Australian Governments. The Interim Planning Target was used as a basis for development of the NGRS, which contains as a first phase mainly 'no regrets' measures (those that have net social benefits, or at least no net social cost). Because the NGRS requires greenhouse abatement to 1988 levels, it represents a more stringent target than the 1990 target in the Framework Convention.

The Ecologically Sustainable Development (ESD) strategy, also endorsed by the Council of Australian Governments on 7 December 1992, sets out the broad strategic and policy framework under which governments are to make decisions cooperatively and to take actions to pursue ESD in Australia.

Both the NGRS and ESD strategies contain a number of response measures relating to the transport sector, including undertaking further research. It was in this context that the then Prime Minister (The Honourable Paul Keating MP) in his 21 December 1992 Statement on the Environment commissioned the BTCE to provide a comprehensive analysis of the range of possible measures for reducing greenhouse gas emissions in the transport sector. This Report, which was completed within the three years envisaged (from the availability of Budget funding in mid-1993), is the result.

In the lead-up to the first Conference of the Parties (COP1) in Berlin, the Commonwealth Government announced, in a March 1995 statement called *Greenhouse 21C* (DEST 1995), additional measures that it would introduce in an effort to bring Australia's performance closer to meeting the Convention's implied target. The package of measures included expansion of the One Billion Trees Program, cooperative agreements between the Commonwealth Government and industry to reduce greenhouse emissions, and acceleration of gas market reform.

The NGRS is currently being reviewed by Australian governments. A final report is to be prepared for consideration by the Council of Australian Governments in the first half of 1997.

THE BTCE'S METHODOLOGY

Many studies of greenhouse gas emissions from the transport sector are limited to qualitative analysis, or lists of potential abatement measures. The BTCE, on the other hand, has tackled the more difficult task of evaluating a range of measures in terms of their relative social costs.

- Basecase ('business as usual') projections by the BTCE indicated that cars would remain the major source of greenhouse gas emissions from the Australian transport sector over the next two decades.
- While car emissions are expected to increase by 10 per cent between 1996 and 2015, emissions from commercial road vehicles (light commercial vehicles as well as trucks) will increase by about 91 per cent. Emissions from aircraft on domestic routes are also projected to grow strongly.
- On the basis of its basecase projections, the BTCE focused its analysis of abatement measures on those affecting cars, commercial road vehicles and aircraft. Planting trees to absorb emissions and resurfacing roads to reduce roughness (and hence fuel consumption) were also investigated to provide alternative policy perspectives.
- The effect of each measure was assessed on the basis of varying degrees of application (intensities) to estimate marginal costs: that is, the additional social cost due to each increase in intensity of implementation.
- A major advantage of estimating marginal costs is that they provide policy makers with information that permits selection of a least-cost set of measures.
- Scientific uncertainties associated with the greenhouse effect, and analytical complications due to the global nature of the effect, preclude reliable estimation of the benefits of reducing greenhouse emissions. The results presented in this Report are therefore more in the nature of a cost-effectiveness study than a cost–benefit analysis.

CHAPTER 2 METHODOLOGY

A key objective of the BTCE's work over the last three years has been to 'push the frontier' beyond the common approach of qualitative analysis of potential abatement measures, or occasional quantification of a single, target level of abatement. An important aim was to extend knowledge of the relative costs of different measures that could potentially be used to reduce greenhouse gas emissions in the transport sector.

Comparison of abatement measures requires estimation of marginal costs, an approach set out in BTCE (1993b). However, this approach is time consuming and often difficult due to the paucity of suitable data. James (1991, p. 13), for example, recognises the difficult nature of the task:

> An economically efficient solution [to minimise the total costs of abatement policies] involves equating the marginal costs of all the … cost functions. *Because of difficulties in prediction and measurement, however, it may be impractical to ascertain the relevant marginal cost functions.* (emphasis added)

The BTCE nevertheless pursued the more complex approach of estimating marginal cost functions, rather than just estimating the costs of achieving single, essentially arbitrary targets. The likely benefits to policy makers of doing so were considered to outweigh the analytical difficulties involved.

A particular advantage of the BTCE's approach is that it provides policy makers with information on costs for a range of possible levels of abatement. It also permits comparisons with costs in other sectors of the economy.

It is not the BTCE's intention to recommend any measures analysed in this Report. Nor should BTCE cost estimates be seen as precluding any other available alternatives for achieving greenhouse gas reductions.

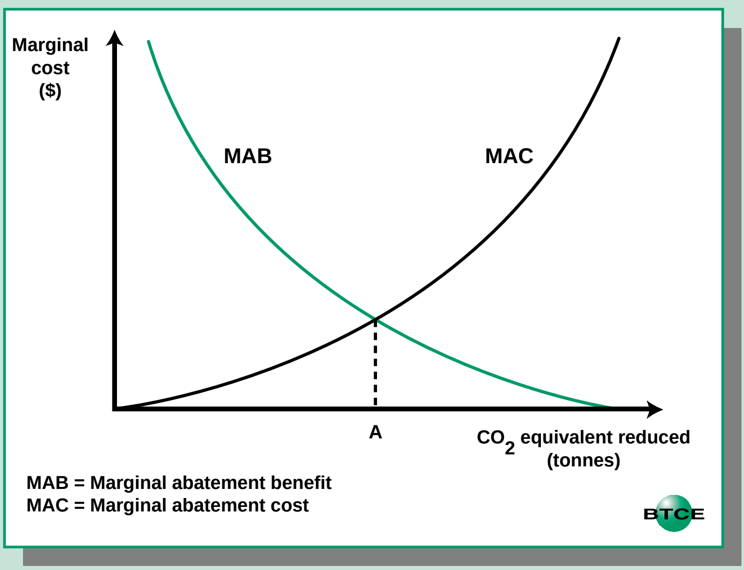
The optimal level of reduction of greenhouse gas emissions

Standard economic analysis of environmental problems is usually presented in terms of a diagram such as figure 2.1. Common (1988, ch. 4) provides a readable exposition for the non-specialist.

As depicted in figure 2.1, when the amount of existing pollution is being reduced, the additional (marginal) cost of any further reduction increases. (An average cost, on the other hand, measures the per unit cost of the total amount of reduction already achieved.) This increasing cost effect is represented by an upward sloping marginal abatement cost (MAC) curve in figure 2.1. The MAC can be thought of as a supply curve of pollution reduction (reduction in pollution treated as a good)—that is, the cost of taking measures to reduce greenhouse gas emissions.

The MAC does not represent or include the cost of any damage caused by the greenhouse effect itself. It should, however, include changes in associated externalities that occur as a direct result of implementing a greenhouse abatement measure, including the positive effect (negative social cost) of reduced noise, noxious emissions, accidents, or congestion.

FIGURE 2.1 OPTIMAL LEVEL OF GREENHOUSE GAS EMISSION ABATEMENT



Source BTCE.

Reductions in negative externalities will effectively shift the MAC curve down. Negative effects (positive social costs) can also occur: for example, the introduction of fuel saving technology may induce a 'rebound effect' of increased travel on the part of motorists who take advantage of reduced travel costs.

As the amount of abatement increases, additional reductions in emissions generate decreasing levels of utility or benefit. For this reason, the marginal abatement benefit (MAB) curve slopes downwards, analogously to a demand curve.

The optimal amount of pollution abatement in a static analysis such as figure 2.1 is determined by the equality of MAC (supply) and MAB (demand). In figure 2.1 the optimal (economically most efficient) level of abatement is the point A, which is determined by the intersection of the two curves.

A major, but often overlooked result that follows from standard economic analysis is that an optimal greenhouse abatement policy does *not* necessarily imply elimination of all anthropogenic greenhouse gases. Economic analysis proceeds on the basis that social (private plus public) costs need to be balanced against social benefits. Unless the net social costs of abatement are zero or negative (the 'no regrets' possibility), society will benefit most by taking some (cost-effective) abatement measures while continuing to produce some greenhouse emissions (and accepting the costs of any increase in global warming or extreme weather patterns).

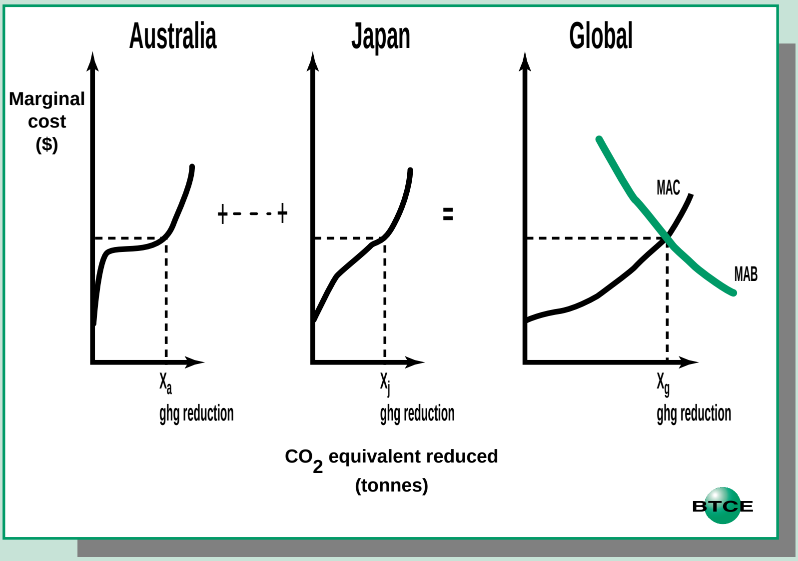
The principle of equi-marginality of costs

The enhanced greenhouse effect is a global phenomenon.

Knowledge of global MAB and MAC functions is required to inform international negotiators of the optimal level of reduction of global greenhouse emissions. It is the lack of such knowledge that has led international negotiators to resort to essentially arbitrary 'targets' in action plans.

Extending to a global level the concept of optimal abatement levels presented in figure 2.1, produces the perspective shown in figure 2.2. The global MAC curve is a (horizontal) sum of the MAC curves of the individual countries in the world, just as supply curves in any market are the sum of the marginal cost (supply) curves of individual producers.

FIGURE 2.2 MARGINAL COST OF REDUCING GLOBAL GREENHOUSE GAS (ghg) EMISSIONS



Source BTCE.

Unless the damage caused by the greenhouse effect is extremely serious, it is unlikely that an optimal level of reduction would involve complete elimination of all global greenhouse emissions.

The total global reduction X_g in figure 2.2 is equal to the sum of all reductions by individual countries. If global reductions in greenhouse emissions are to be shared between countries in an economically efficient manner, then each country should reduce its emissions until the marginal cost of doing so equals the marginal costs of abatement in the other countries. This is the standard condition of equi-marginality of costs.

The condition of equi-marginality means that, in the absence of distortions such as cross-subsidisation of domestic consumers of electricity (or other breaches of the usual perfect competition assumptions), countries that face higher marginal costs of abatement should reduce emissions less than those which can achieve additional reductions more cheaply. Reductions on this basis would ensure that global emissions were reduced at least cost to the world as a whole. BIE (1995) reviews the difficulties inherent in alternative approaches to international burden sharing based on principles of equity.

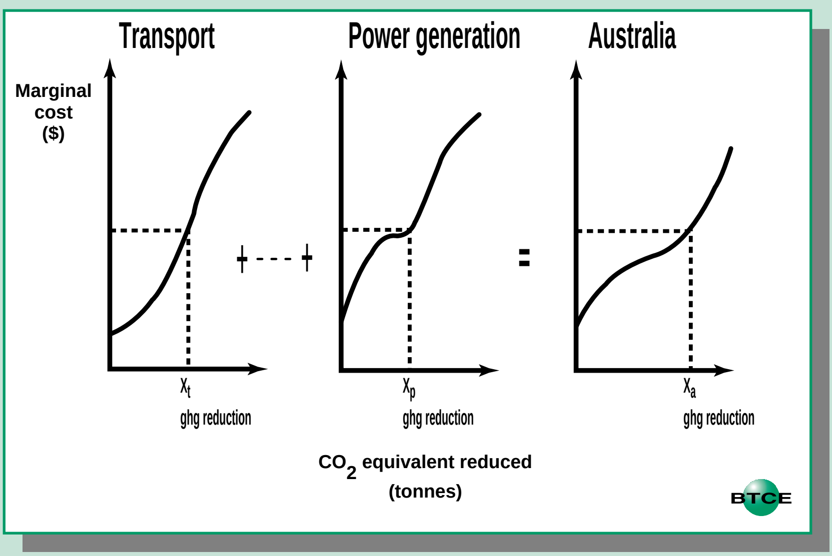
If international agreement were reached on reducing global greenhouse emissions, either to optimal levels (point X_g in figure 2.2) or even to some arbitrary target, Japan and Australia should reduce their emissions by X_j and X_a respectively. If Japan's MAC were flatter because it had lower abatement costs than Australia, it would be more efficient for it to reduce its emissions more than Australia, so that X_j would be greater than X_a.

Extension of the concept of equi-marginality within individual countries permits economically efficient allocation of each country's abatement share to different sectors of the economy. Figure 2.3 illustrates this extension for Australia.

A major point implicit in figure 2.3 is that it would be inefficient to reduce greenhouse emissions by equal quantities or percentages in all sectors of the economy.

Abatement measures can be achieved at lowest overall cost to the Australian community only on the basis of reductions in all sectors up to the point where the marginal costs of doing so are equalised.

FIGURE 2.3 MARGINAL COST OF REDUCING AUSTRALIAN GREENHOUSE GAS (ghg) EMISSIONS

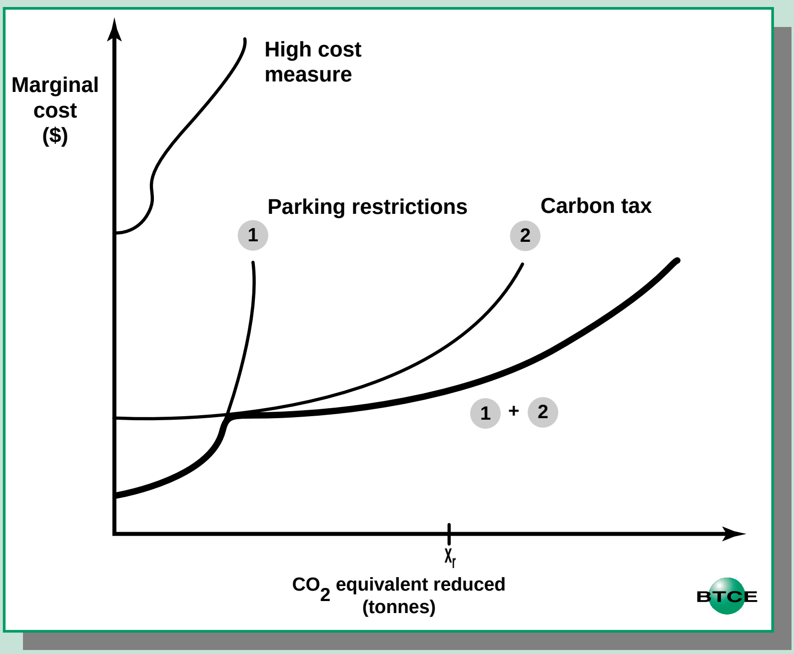


Source BTCE.

For an informed policy response, it is therefore essential to have available estimates of marginal cost functions for measures in all sectors of the Australian economy before specific abatement measures are adopted.

A further extension of the equi-marginal approach permits allocation of abatement shares to different measures within an individual sector such as transport. Figure 2.4 illustrates two possible abatement measures. Parking restrictions in the central business district of a city can be assumed to involve rapidly increasing costs as it becomes increasingly onerous to achieve additional reductions in emissions. Alternative policies such as a carbon tax may permit a greater degree of latitude in adjustment by motorists (for example, some reduction in car usage through trip linking or moving residence closer to work) so that the marginal cost curve is flatter. For any pre-specified reduction in emissions in the transport sector, the two individual curves can be used to determine the economically efficient share in emission reductions that each measure needs to contribute.

FIGURE 2.4 ILLUSTRATIVE COMPOSITE MARGINAL COST CURVE FOR TRANSPORT SECTOR



Source BTCE.

By implication, the marginal cost approach illustrated in figures 2.2 to 2.4 requires that the marginal cost functions of all possible policy measures are identified to ensure accurate specification of the composite, aggregated curve. However, if the reduction level required is not very large, more expensive measures can be omitted without affecting the analysis or policy formulation. Because they appear relatively high up the vertical axis, such cost curves do not become relevant to the composite curve until high levels of abatement are reached.

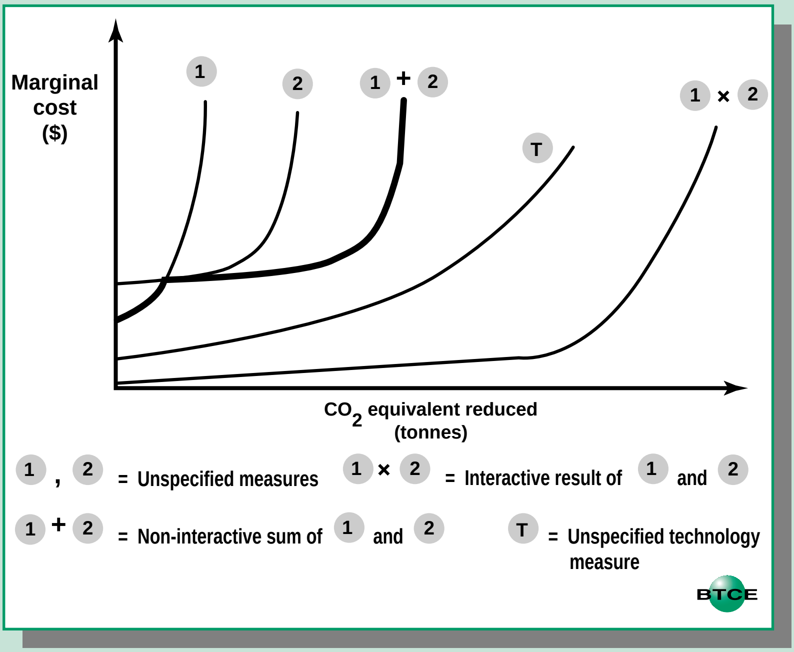
For example, in figure 2.4, to specify the composite curve fully, the (unspecified) policy labelled 'high cost measure' needs to be included. But if the required level of emission reduction is only X_r for the transport sector, then it would be inefficient to implement the high cost measure. The required reduction can be achieved efficiently by implementing only the two lower cost instruments. A particularly useful aspect of this approach is that it is not necessary for researchers or policy makers to determine fully the marginal cost functions for all possible policy instruments, provided that the required reduction in total emissions is not very large. Back of the envelope calculations can be used to identify likely low cost policies, and these can be evaluated in greater detail.

A corollary of the approach illustrated in figure 2.4 is that even an economically efficient abatement measure such as a carbon tax may not necessarily be the cheapest alternative. Common (1995, p. 9) observes that much of the greenhouse abatement literature presumes that uniform taxation of carbon dioxide emissions will achieve abatement at the lowest total cost. Analyses that are based on this presumption confuse efficiency in resource allocation with the cost of implementation.

Figure 2.5 shows a marginal cost function for a relatively efficient instrument T (technology), and for a number of other (unspecified) measures that involve higher marginal costs at all levels of abatement. If there are synergies between some of the higher cost measures, then their combined effect may result in a composite marginal cost function that lies *below* the one for the technology instrument. One example might be the interactive effect between the accelerated scrapping of old vehicles and higher emission and fuel consumption standards for new vehicles.

Ultimately, empirical analysis of a range of options is required, including combinations of measures, in order to determine the least-cost approach.

FIGURE 2.5 ILLUSTRATION OF INTERACTIONS BETWEEN ABATEMENT MEASURES



Source BTCE.

Analytical complications in the case of greenhouse gas emissions

Unfortunately, greenhouse issues cannot be analysed satisfactorily using the simple conceptual framework represented in figures 2.1 to 2.3. In the words of Common (1991, p. 18), the complexities of the greenhouse effect make ‘the search for optimality of questionable value’.

The optimal level of abatement shown in figure 2.1 is determined by the intersection (that is, equality) of the marginal benefit (MAB) and marginal cost (MAC) curves. Both the costs and benefits are defined on the horizontal axis in terms of anthropogenic *emission* levels. But damage from the enhanced greenhouse effect depends on global atmospheric *concentrations* (the total of both natural and anthropogenic) of greenhouse gases.

An equally fundamental problem is the lack of a reliable benefits (MAB) curve.

The benefits of reducing greenhouse gas concentrations are identical to the damage avoided. However, there are two major areas of uncertainty in determining the physical damage that might be caused by the greenhouse effect.

Firstly, scientific knowledge of the extent and timing of climatic change is still rudimentary. Secondly, global climate change from the greenhouse effect is not the sole determinant of local weather patterns.

The local effects of global warming are expected to differ by latitude. Effects such as the El Niño (Southern Oscillation) effect in the Pacific (particularly relevant to Australia), variations in the sun's output of energy by small amounts over an 11-year cycle as well as variations over longer periods, industrial emissions of sulphur dioxide in northern Europe, volcanic eruptions on the scale of Mt Pinatubo in 1991, and increased flows of fresh water entering the Atlantic (Walker 1995, p. 20) are also likely to play an important role. Not all countries will be affected in the same way.

The economic effect of climate change is particularly difficult to predict. Waggoner (1993) provides a useful list of examples of nonlinear responses to climate change in the agricultural sector. Crops, for example require temperature and moisture conditions within threshold ranges which change as seeds germinate and plants grow. Even carbon dioxide concentrations affect plant growth in different, nonlinear ways for different species. Plant pests and animals may also react to climate change in ways that cannot be extrapolated from current behaviour. Fisher and Hanemann (1993) review some of the complications of nonlinearities in the economic valuation of the effects of climate change.

Even if climatic change could be more precisely specified geographically, the determination of damage to the infinite range of human needs and activity (not to mention to non-traded goods such as biodiversity) poses an almost intractable problem.

Nordhaus (1991, p. 930) further points out that:

> human societies thrive in a wide variety of climatic zones. For the bulk of economic activity, non-climate variables like labour skills, access to markets, or technology swamp climatic considerations in determining economic efficiency.

In the case of large countries such as Australia, regional differences increase the analytical uncertainties. Whether a region is beneficially or adversely affected depends on its ability to sustain variations (both increases and decreases) in temperature and rainfall.

In estimating sectoral benefits of greenhouse abatement for the USA, Nordhaus (1991, pp. 932–933) comments that:

> Cold regions may gain while hot regions may lose; investments in water skiing will appreciate while those in snow skiing will depreciate. Climate change is likely to produce a combination of gains and losses with no strong presumption of substantial net economic damages. This is not an argument in favour of climate change or a laissez-faire attitude to the greenhouse effect. Rather, it suggests that a careful weighing of costs and damages will be necessary if a sensible strategy is to be devised.

Nordhaus (1991, p. 933) estimates that the damage from a 3°C warming scenario (considered a 'best estimate' at the time, but about 30 per cent above current estimates) would be around 0.25 per cent annually of national income for the USA, and extrapolates it to other countries. Acknowledging that he has omitted difficult to quantify areas, he states that his 'hunch is that the overall impact upon human activity is unlikely to be larger than 2 per cent of total output'. However, Cline (1991, p. 225) criticises the low value of the estimate on the grounds that Nordhaus has apparently omitted loss in consumer surplus, which would be high for price-inelastic foodstuffs overall (especially for a food importing country).

A further complication is that the MAB curve in figure 2.2 is the vertical sum of the benefit curves for individual countries, reflecting the joint nature of the benefit to each country of global reductions in greenhouse concentrations or emissions. Because atmospheric models can currently predict climatic effects at the local level only very approximately, even benefit functions for individual countries are likely to involve a significant degree of error.

Because of the problems involved in estimating a reliable benefits function (MAB), the BTCE analysis was limited to estimation of the costs (MAC) of reducing greenhouse gases. It is therefore most accurately described as a cost-effectiveness study, not a full cost–benefit analysis.

Carbon taxes, Pigovian taxes, and property rights

'Externalities' is a term that is seldom defined in economic texts. Baumol and Oates (1988, pp. 15–18) propose formal conditions that essentially translate into stating that a negative externality occurs when one individual engages in an activity that imposes costs on another, and the victim cannot normally be compensated for them through the market mechanism. The usual example of such 'market failure' is the smoky factory that affects those around it. Positive externalities provide benefits to those affected by them.

Greenhouse emissions have the additional characteristic that they affect everyone on the earth because of their ultimate mixing in the earth's atmosphere. But because climate change is expected to differ by region, not everyone will be affected equally.

Economics texts typically illustrate one method of correcting externalities, like pollution, by a shift upward of the supply (marginal private cost) curve by an amount equal to the costs imposed on society (marginal public cost). This correction presupposes that a government imposes a tax on polluters to ensure that the net outcome of their activities is socially (Pareto) optimal. Imposition of such Pigovian taxes, named in recognition of their first exponent, A.C. Pigou (1932, p. 192) itself results in an economically efficient solution. To maintain this socially efficient solution, victims should not receive in compensation the revenue raised by imposing a Pigovian tax on polluters (Baumol & Oates 1988, p. 15).

Partly in reaction to Pigou's approach, Coase (1960) proposed through a set of examples an alternative that did not require government intervention. The so-called Coase theorem requires only that there be a legal allocation of the property rights affected by the externality in question. (Either the factory should have a right to pollute, or the victim should have a right to enjoy clean air.) It follows from Coase's fairly limiting assumptions that the initial allocation (either to the polluter or the victim) of these rights does not matter from an efficiency perspective, as long as the rights can be freely exchanged. Bargaining between the polluter and the victim will result in an efficient level of pollution.

A tax on the carbon content of fuel **(chapter 9)** could be imposed in the Pigovian manner. But a Pigovian carbon tax would require knowledge of the damage caused to society by those emitting greenhouse gases. Because of the large number of uncertainties involved in estimating the damage that might be caused by greenhouse emissions, a Pigovian approach would in practice also be subject to considerable uncertainty.

In cases where there are many polluters or many victims, the Coasean approach becomes unworkable because of the high transactions cost that would be incurred in the coordination of common bargaining positions on either side. In the case of greenhouse policy, the Coasean approach is further complicated by the fact that polluters are simultaneously victims, although pollution and suffering are not equal for all parties.

An alternative that has gained prominence in recent years is the use of tradable rights in emission entitlements (BIE 1992). Tradable permits overcome a major disadvantage of carbon taxes because they permit more flexibility: polluters can choose to reduce emissions, create carbon sinks, or pay for the right to emit above a benchmark quota.

Although tradable permits offer a least-cost method of allocating an emission quota amongst polluters, they cannot of themselves determine an economically efficient quota. That is, a system of tradable permits requires an external authority such as a government to determine and enforce the optimal quota or level of pollution to be traded. Determination of an efficient quota (total quantity of pollution) is simply the mirror problem of identifying an efficient Pigovian tax (price paid for a given quantity of pollution), and therefore suffers from similar practical problems of estimation. Successful introduction of tradable permits on an international basis would also require purchasers to be confident (in the face of scientific and political uncertainty) that emission rights will continue to be negotiable into the future without loss of value.

International negotiations have so far focused on essentially arbitrary levels of abatement and carbon taxes. (Except by pure coincidence, specific taxes determined without reference to damage costs would be economically inefficient and are likely to misallocate national resources.) Adoption of such second-best solutions is understandable in the face of policy uncertainties. However, once a policy decision has been taken to reduce emissions, even second-best solutions need to be compared with other, alternative second-best solutions to ensure that national implementation can be achieved at least cost to the community.

'Recycling' revenues from carbon taxes and other measures

Carbon taxes have the potential to raise considerable sums in revenue, but other instruments such as road user charges (chapter 18) could also increase government revenues.

The theoretical justification for carbon taxes rests heavily on their efficiency (Pareto optimality) as greenhouse gas abatement instruments.

Assuming that the level of tax determined by policy makers approximately equals the discounted future marginal damage (a Pigovian tax) caused by the greenhouse effect, then the revenue raised from the tax should not be recycled to the victims (Baumol & Oates 1988, pp. 23–25). The tax itself corrects any externality through the price signal imposed on polluters.

In the case of carbon taxes designed to reduce greenhouse damage, the polluters (those who use fossil fuels either in transport or other sectors) are virtually identical to the victims (the community as a whole, including all taxpayers). Because tax revenue raised from greenhouse polluters must inevitably be recycled in some form to the victims (unless it is donated to foreigners over and above other payments) the theoretical underpinnings for a carbon tax do not hold.

Additional carbon tax revenues could be used to offset the burden of other taxes on the community (fiscal neutrality), to increase government spending domestically or overseas (including on energy saving technology research), or to reduce Budget deficits or increase surpluses. The distributional consequences of these alternatives differ considerably.

Analysis of welfare effects for Australia would need to be carried out on a case by case basis using a suitable macroeconomic model. It would be necessary to ensure that the use of revenues did not stimulate additional activity in the economy so as to increase greenhouse emissions above the reduction achieved from the carbon tax.

If revenue recycling increases the community's welfare, then the income effect of a carbon tax is likely to be offset, or even neutralised because of the virtual identity of polluters and victims. A similar effect will occur if revenues are recycled to increase general government spending or to decrease the Budget deficit, particularly if a wide cross-section of the community benefits.

Any use of revenues from carbon taxes to subsidise research into energy efficiency or to expand or improve public transport also raises complex issues of non-optimality. If the tax imposed reflects the public costs of greenhouse damage, then the behaviour of polluters will have already been modified to an optimal level. Further subsidies for research to reduce emissions or to support adaptation measures would be non-optimal. Any hypothecation (that is, prior allocation of revenues to specific expenditure programs) of tax revenues would also reduce the ability of governments to allocate revenues to areas of greatest benefit to the community.

Proponents of carbon taxes sometimes argue that their imposition will increase welfare (even if revenue collected falls) if they replace other, more distortionary taxes. If such possibilities exist, then they should be implemented regardless of greenhouse considerations. Any resulting greenhouse benefits would make them 'no regrets' measures. An additional carbon tax of the Pigovian variety could then be applied to match any residual public costs of greenhouse damage, subject to the caveats outlined above.

Because the BTCE adopted a partial equilibrium approach that did not lend itself easily to exploring the complexities of revenue recycling, the issue has not been pursued in analysis of individual measures presented in the body of this Report.

General equilibrium modelling versus partial equilibrium analysis

Many Australian studies that evaluate the costs of reducing greenhouse gases have employed a 'top-down' approach, using some form of macroeconomic or general equilibrium model. General equilibrium analysis has probably been at least partially favoured by researchers because use of existing models can minimise the additional analytical and empirical work required.

Given the complexity of the greenhouse effect, an ideal model or set of interactive models would need to represent in detail each sector of a national economy, as well as taking into account broader consequences at the international level, including trade patterns. Feedback effects of climate change on sectors such as agriculture or housing (through weather patterns or increased vegetative growth because of higher carbon dioxide concentrations) would also need to be included for models used for long-run analysis.

The BTCE considered at the beginning of its study the relative advantages and disadvantages of using a general equilibrium model versus partial equilibrium analysis.

General equilibrium models possess the ability to take into account interactions between different sectors of the economy, and to explore distributional effects. This is a major advantage in the case of measures such as a carbon tax, which has economy-wide effects whether it is imposed solely within the transport sector or more generally. Partial equilibrium analysis, on the other hand, has the advantage of facilitating detailed exploration of the effect of a specific measure within a sector of the economy. It is also arguable that a partial equilibrium analysis provides a reasonable 'first approximation' to a general equilibrium result, where the effects of a measure are confined largely to the sector being analysed.

From a conceptual point of view, either partial or general equilibrium analysis would provide a suitable analytical framework. Nevertheless, the BTCE chose to employ a conventional partial equilibrium, cost-effectiveness approach mainly because general equilibrium models available in mid-1993 did not appear to possess as much detail on the transport sector as desired.

It was also felt during the initial stages of the project that the workings of large general equilibrium models were not generally understood by policy makers. This perceived lack of transparency was (subsequently) a primary reason for the organisation by the Department of Environment, Sport and Territories of a workshop specifically to narrow the communication 'gap' between economists and policy makers, and to reconcile the various modelling results being generated (DEST 1994, pp. 3, 90). Commenting on the 'black-box' view that some non-specialist policy makers have of models, Hamilton (1994, p. 83) said that 'policy makers faced with environmental decisions generally do not feel comfortable with methods that attempt to roll all of the effects of a policy action into one measure'.

Despite adopting a partial equilibrium approach, the BTCE has sought to incorporate a dynamic aspect to provide information on changes in costs over time. Results are presented for each measure as 'snapshots' of cost functions for the years 2000, 2005, 2010 and 2015. Comparison of costs in 2000 and 2015, for example, provides an indication of the relative suitability of an abatement measure in the short or the long term. Snapshot years are not intended to suggest targets.

Economic costs

The costs used throughout this Report are economic costs (see Glossary). That is, they are based on opportunity costs rather than just financial costs. Where possible, changes in consumer surplus and producer surplus have been included in cost estimates.

Although the adjective 'economic' is not generally used, the term 'cost' in this Report is understood to mean 'economic cost', unless stated otherwise. Economic cost is understood irrespective of whether reference is to private, public or social costs.

Where costs have been calculated on a national basis, they refer to social (economic) costs. Social costs can normally be determined by aggregating the (private) economic costs of individuals, and adjusting the total. Where individual behaviour generates externalities, for example, their value needs to be added in to reflect the (public) cost or benefit to society as a whole. Transfer payments such as taxes (e.g. the fuel excise included in the retail cost of petrol to an individual), are normally netted out.

Unless stated otherwise, all costs (private, public and social) are expressed in present values (1995–96 $) using a real discount rate of 10 per cent (see below).

In general, therefore, the costs of abatement for any measure analysed in this Report refer to the net present value of social economic cost in 1995–96 Australian dollars.

Incremental costs

Economic analysis relies heavily on marginal concepts to solve optimisation problems such as determining a least-cost set of greenhouse abatement instruments.

Marginal cost is normally defined in terms of differential calculus as the first derivative of a total cost function with respect to some output variable (such as the amount of greenhouse emissions reduced). The concept of differentiation is based on changes that are infinitesimally small. By definition, therefore, changes in output variables should be very small in order to obtain accurate estimates of marginal costs.

In practice, economic variables are not likely to be perfectly divisible. Technology, for example, can usually be applied only in discrete 'lumps', as in chapter 4 where cars are fitted with four types of emission control technology. Each technology is either applied or it is not; it cannot be divided into smaller 'amounts'. Even carbon taxes would in practice be applied in discrete units, with the smallest incremental unit per litre of fuel being 1 cent.

The estimates presented in this report are therefore more accurately described as 'incremental costs' rather than 'marginal' costs. However most readers are more familiar with the term 'marginal cost', and it is conceptually identical to incremental cost in its practical application. 'Marginal cost' has therefore been used throughout the Report to avoid confusion.

Estimating marginal social costs

Marginal social costs for all measures evaluated in this Report were calculated on the basis of 'intensities', or degree of application of the measure concerned. As the intensity of application increases, emissions are correspondingly reduced from basecase levels.

An example of a relatively natural intensity is the carbon tax **(chapter 9)**, where the rate was increased progressively to reduce emissions further. In the case of planting trees **(chapter 14)**, the intensity chosen was incremental increases in the proportion of total transport emissions sequestered. Other instruments involved a greater degree of arbitrariness in choice of intensity. Technology instruments, for example, were defined in terms of increased amounts of technology applied (for example, chapter 4). Intensification of the vehicle labelling and road user charges measures was on a jurisdictional, geographic basis **(chapters 8 and 18)**.

Estimation of marginal costs is best illustrated using figure 2.6 and table 2.1.

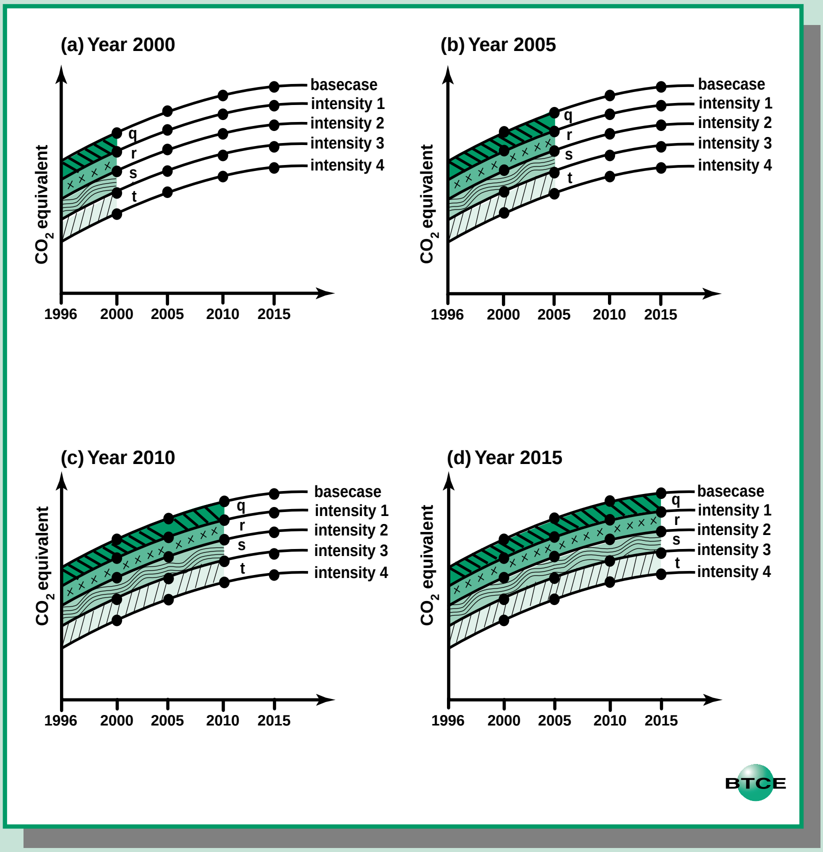
Basecase emissions (zero intensity of application of a policy measure) of greenhouse gases from the transport sector are known for each year from 1996 to 2015 (**appendix III**, and below).

Application of the first level of intensity of an abatement measure would reduce emissions in each year from 1996 to any given future year (for example 2000). These annual reductions can be summed to give a cumulative reduction from basecase emissions from 1996 up to and including the year 2000, and are represented by the hatched area labelled q in figure 2.6(a). A further reduction of r can be achieved by applying intensity level 2. The cumulative reduction in emissions obtained at intensity level 2 (which includes application of intensity level 1) is therefore q+r tonnes of CO_2 equivalent emissions. Similarly, intensity level 3 (which includes levels 1 and 2) will yield a cumulative reduction in emissions of q+r+s tonnes of CO_2 equivalent. These amounts have been entered in column 2 of table 2.1.

By identifying the social (public plus private) costs of each intensity level of a measure, it is possible to complete the corresponding rows of column 4.

Application of a measure at intensity level 2, for example, will achieve a cumulative reduction in emissions of q+r tonnes of CO_2 equivalents. Because the social costs of implementation can be expected to be incurred

FIGURE 2.6 ILLUSTRATIVE DERIVATION OF REDUCTION IN CUMULATIVE EMISSIONS AT DIFFERENT INTENSITIES OF APPLICATION OF AN ABATEMENT MEASURE



Source BTCE.

in a number (or all) of each of the years from 1996 to 2000 inclusive, they need to be expressed in comparable values. All costs were therefore expressed in terms of present values in 1995–96 $, using a discount rate of 10 per cent. Because they are expressed in the common numeraire of 1995–96 $, they can be added to give a measure of the cumulative social cost of $\$_{1995\text{-}96}$(k+l) of achieving an emission reduction of q+r tonnes of CO_2 equivalent in greenhouse gases.

By calculating differences in cumulative emission reductions, as well as differences in cumulative social costs between intensity levels, incremental changes can be calculated. These incremental changes are shown as columns (3) and (5) respectively in table 2.1. Division of values in column (5) by those in column (3) provide the marginal cost estimates given in column (7).

Repetition of this procedure for other snapshot years is illustrated in figures 2.6(b) to 2.6(d). Calculation of corresponding marginal costs would be repeated using the procedure set out in table 2.1. Although marginal costs could be calculated for each year of the study period 1996 to 2015, they were estimated only for the snapshot years 2000, 2005, 2010, and 2015.

TABLE 2.1 TITLE OF ABATEMENT MEASURE: SOCIAL COSTS[a] IN 20XX OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Description of intensity[b]	*Cumulative reduction: CO_2 equivalent*	*Change in cumulative reduction: CO_2 equivalent*	*Social cost of cumulative reduction*	*Change in social cost*	*Average social cost[c]*	*Marginal social cost[d]*
(Units)[e]	*(tonnes)*	*(tonnes)*	*($)*	*($)*	*($ per tonne)*	*($ per tonne)*
0 (basecase)	0	0	0	0	0	0
1	q	q	k	k	k/q	k/q
2	q+r	r	k+l	l	(k+l)/(q+r))	l/r
3	q+r+s	s	k+l+m	m	(k+l+m)/(q+r+s)	m/s
4	q+r+s+t	t	k+l+m+n	n	(k+l+m+n)/(q+r+s+t)	n/t

a. All costs are net present values (1995–96 $) for costs up to and including the year 20XX, using a discount rate of 10 per cent. Terms such as ‘social cost’ are defined in the Glossary at the end of this Report.

b. Description of intensity (see tables in each chapter following). Higher intensity levels would normally include preceding levels (level 3, for example, includes application of levels 1 and 2). The basecase (zero intensity) is shown here for illustrative purposes only. Reductions in emissions are calculated as reductions from basecase levels.

c. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

e. Units may differ for various abatement measures. But consistency is required for emissions and costs to ensure correct calculation of average and marginal costs. If emissions are expressed in million tonnes, costs need to be expressed in $ million.

Source BTCE estimates.

Figure 2.6 is intended to be illustrative: it should not be interpreted to mean that cumulative reductions in emissions between 1996 and 2000, for example, will be the same as those achieved between 2010 and 2015. Abatement measures such as emission saving technology for cars **(chapter 4)** would be less effective in the short run, with larger reductions achievable only in the longer term **(figure 4.2)** as the technology spread through the car fleet.

This timing effect highlights the problem of setting short-term greenhouse gas abatement targets. Because the effect of some measures (e.g. a carbon tax) is felt more quickly, they may be adopted in preference to those whose full effect is relatively slower. If the 'slower' measure were cheaper in the long run it would be preferable, but would be likely to be overlooked if short-term targets were the sole criterion used by policy makers.

An alternative method for estimating marginal costs would have been to estimate changes in emissions and costs between years for each intensity level, rather than cumulatively from 1996 to a snapshot year. For example, the marginal cost for the year 2015 could have been estimated as the difference in emissions and costs in the year 2014 and the year 2015. Such an approach would not have provided information on the costs of cumulative reductions. Where costs are incurred only in early years (e.g. 1996), calculation of marginal costs between years would generate a figure that ignored resources used to achieve a between-year change (e.g. 2014–2015) in emissions.

Marginal, average and total costs

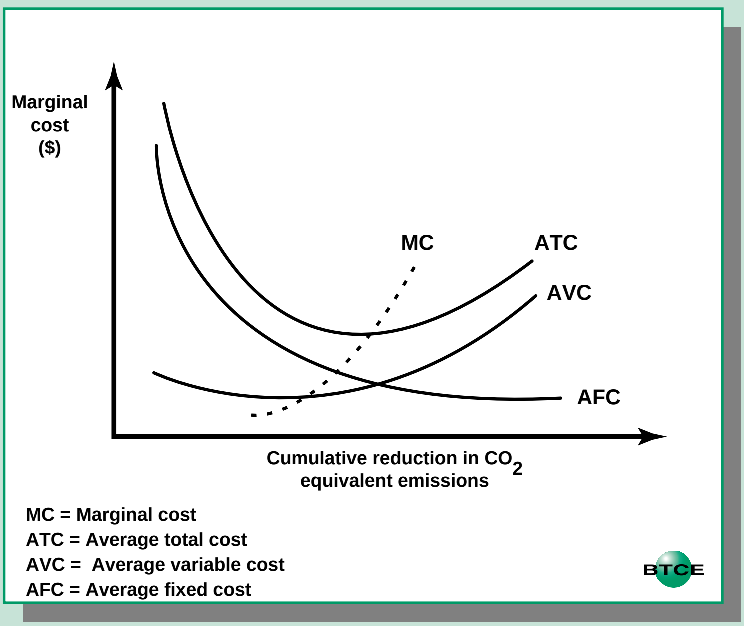
Marginal cost curves are essentially supply curves. In the case of the measures analysed in this Report, they represent the supply of a 'good': the cumulative reduction in CO_2 equivalent emissions.

In presenting the theory of the firm, economics textbooks typically stress that a firm's supply curve begins where marginal cost exceeds average cost. Figure 2.7 illustrates the situation. Marginal cost (MC) curves will at some stage intersect first the average variable cost (AVC) curve from below at its minimum point, and then pass through the minimum point of the average total cost curve (ATC), where the distance between the AVC and ATC curves represents average fixed costs (AFC) at a given level of output. In the long run (when all costs are variable), a firm will supply its output only if the price received is above the point of intersection of MC and ATC, assuming the usual conditions of perfect competition. In the short run, a firm may continue to produce if the price for its output is above AVC, in order to cover at least some of the fixed costs. If the price received does not even cover variable costs (MC < AVC) the firm will cease production.

The standard textbook analysis of average and marginal costs presupposes receipt of revenues by the firm.

Because the analysis in this Report is more in the nature of a cost-effectiveness study (with benefits expressed only as cumulative reductions in CO_2 equivalent emissions rather than in dollars of social benefit), the textbook approach cannot be applied exactly. Analysis of greenhouse gas abatement measures does not consider whether the supply of cumulative reductions in emissions is such that social costs are 'recovered' through a revenue stream of social benefits.

FIGURE 2.7 MARGINAL AND AVERAGE COST CURVES



Source BTCE.

Nevertheless, the potential existence of large fixed costs for some measures, such as upgrading railways to attract intercapital road freight **(chapter 12)**, means that marginal cost curves themselves are not necessarily sufficient to ensure selection of a least-cost measure from options available. For reduction levels where marginal costs may lie below average costs, it is necessary, for any given level of abatement, to check the total cost of implementation, because a low marginal cost may mask significant expenditure on fixed cost items.

Choice of discount rate

Benefits and costs that occur in the future can be made comparable with those that occur in the present through the use of a discount rate. The process of discounting is necessary because a certain amount of dollars today is worth more than the same amount of dollars at some time in the future (the dollars invested today would yield a larger number of dollars in the future). Discount rates are used to convert future costs and benefits into present values and can therefore be regarded as an exchange rate that reflects the trade-off between the present and future value of money.

The concept of discounting is discussed in most elementary economics texts, including McCloskey (1985, pp. 529–531). Brealey and Myers (1991) cover various complexities of financial appraisals, including adjustment for different risk profiles and taxation effects.

Although the concept of discounting is straightforward, and various techniques have been developed for determining discount rates for use in financial appraisals carried out by individuals or firms, there is no consensus regarding appropriate *social* discount rates. A social discount rate, rather than a financial discount rate, is required to calculate the present values of the *social* costs and benefits used in this Report.

A basic concept associated with all discount rates is that of 'time preference'. Individuals have a limited lifetime and are not likely to look very far ahead for returns on investments. Society, on the other hand, has a greater sense of permanency because it is constantly replenished by the birth of new individuals. It will therefore look further into the future for returns on investments or trade-offs between present and future consumption. The consequence of the difference between private and social rates of time preference is that society would tend to discount the future less heavily than individuals and would have a lower discount rate.

The opportunity cost concept, on the other hand, suggests that it would be difficult for society to apply a lower discount rate to public sector projects than for private sector projects, because capital which could be more profitably employed in the private sector would then be attracted to the public sector.

Social discount rates can be determined from the perspective of either consumption or investment income. The two major approaches relevant to consumption and investment income, respectively, are known as the Social Rate of Time Preference (SRTP), and the Social Opportunity Cost of Capital (SOCC). Sugden and Williams (1978, pp. 211–228) discuss the issues involved, including methods for reconciling the two approaches. But there is no one, 'correct' social discount rate.

Any positive, non-zero rate of discount will favour consumption by the present generation. It is sometimes argued that very low, or even zero rates of discount should be used in order to take into account the preferences of future generations. Such arguments for 'intergenerational' equity are not fully convincing because they dictate that individuals must forgo consumption in favour of their (and others') successors on the basis that present society has perfect knowledge of the preferences of future generations. Apart from any ethical issues, future generations are also likely to be wealthier and to have access to more advanced technologies. They are therefore likely to be able to adapt to, or offset negative legacies such as climate change.

Resource constraints precluded estimation of appropriate social discount rates for this Report. A rate of 10 per cent was used for each measure. This rate probably represents an upper bound to a social discount rate in Australia, and is more of a SOCC than an SRTP.

Because all costs of implementing greenhouse abatement measures were estimated in 1995–96 prices (1995–96 $), the 10 per cent discount rate used is effectively a real rate.

Measurement of emissions

Emissions from the transport sector can be measured in a number of ways.

It is common to measure only end-use emissions: those resulting solely from the operation of the vehicle, including evaporative emissions. While end-use emissions provide legitimate comparisons between similar vehicles, this approach can result in misleading conclusions when petrol-driven vehicles and electric cars or trains are compared, because emissions from electricity production are not accounted for.

A broader definition is the 'full fuel cycle' approach, which includes not only end-use emissions, but also those resulting from extraction or production of the energy source (coal or oil), power generation (including electricity), and distribution (including transport of petrol supplies to service stations). An even broader approach could include the energy used to manufacture and scrap cars and other vehicles (the 'life cycle' approach), or even a 'system cycle' which includes emissions produced in building and maintaining roads and other transport infrastructure.

Which level of analysis is best depends on the objective and framework of the analysis. It is arguable that a comprehensive analysis should be based on a full 'carbon budgeting' approach akin to something like the 'system cycle'. However, an all-inclusive approach would involve a potentially unlimited number of sectors outside transport, of greater relevance to an economy-wide rather than a sectoral analysis.

For ease of analysis of the transport sector and consistency with IPCC definitions, marginal costs in this Report are generally based on changes in end-use emissions. Emissions from electric trains and trams have been estimated on a full fuel cycle basis using the factors presented in BTCE (1995c, ch. 6). For comparability, alternative fuels **(chapter 17)** have also been analysed on a full fuel cycle basis.

Many studies of greenhouse gas emissions are based solely on the change in output of carbon dioxide due to an abatement measure. However, such studies do not take sufficient account of the complex chemistry of transport emissions and the intricate relationships between local and global emissions. Results obtained may therefore be misleading.

Wherever possible, the BTCE's analysis was based on all of the major greenhouse gas emissions from transport. For the purposes of calculating marginal costs, it is the change in CO_2 equivalent emissions (appendix IV) that has been used.

The basecase for greenhouse emissions

In order to evaluate the effectiveness of abatement measures over some future period, it is necessary to establish a basecase (or 'business as usual' scenario) of greenhouse gas emissions. A basecase is usually estimated on the basis of projections made on the assumption that no specific action is taken to reduce greenhouse emissions.

Econometric estimation of emissions as far into the future as 2015 is obviously prone to considerable uncertainty and error. (It is not dissimilar to the uncertainties involved in scientific modelling of climate change, but with the added complication of unpredictable human behavioural response.) Long-term econometric models are usually specified in terms of only the key economic variables such as income and price, underpinned by specific modelling of factors such as expected fuel efficiencies of new vehicles over the forecasting period. Short-term economic influences such as variations in interest rates were assumed to remain constant.

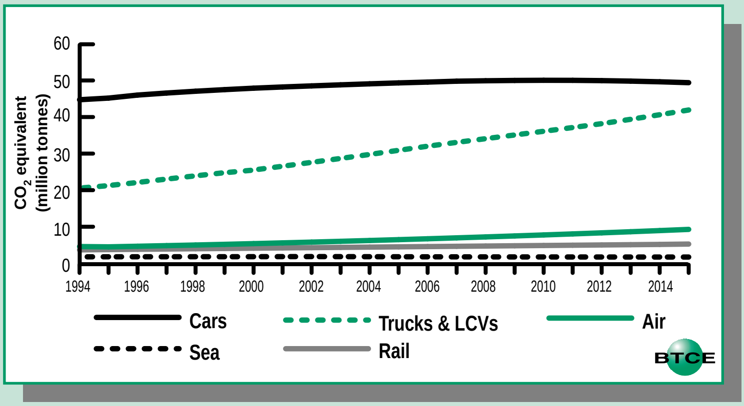
Detailed long-term basecase projections of Australian greenhouse emissions from the transport sector were published for the first time in BTCE (1995c).

The picture that emerged from BTCE (1995c, fig. 7.1, p. 131) was that greenhouse emissions from cars would stabilise over the period 1996–2015, but that emissions from trucks and light commercial vehicles (LCVs) would grow rapidly. These projections indicated that by 2015 emissions from trucks and LCVs combined would be as great as those from passenger vehicles. Emissions from domestic aircraft movements were also expected to grow strongly, with rail and maritime emissions remaining comparatively low.

The forecasting models used in BTCE (1995c) relied on robust but rudimentary models of the car and commercial vehicle fleets, which took no account of deterioration of vehicles as they aged—either in terms of fuel efficiency or increased emission of pollutants. Specification of scrapping equations was embryonic. A number of improvements, including better information on likely technology, have therefore been introduced in this Report, through use of models such as CARMOD, TRUCKMOD and AVMOD. Projections for rail and maritime emissions have not been re-estimated. Revised basecase projections are given in appendix III.

Figure 2.8 presents basecase emissions for the Australian transport sector. Greenhouse emissions from cars reveal growth of about 10 per cent between 1996 and 2015, while those from commercial road vehicles increase by about 91 per cent. On the basis of these revised projections, emissions from road freight vehicles are not expected to match those of cars until some time after the year 2015.

FIGURE 2.8 PROJECTIONS OF CO_2 EQUIVALENT EMISSIONS FROM AUSTRALIAN DOMESTIC TRANSPORT



Sources BTCE 1995c, 1996a, 1996e; BTCE estimates.

Although basecase emissions from fuel used by international transport are recorded in appendix III, abatement measures analysed were limited to those directed at reducing domestic emissions, because of lack of international agreement on the attribution to individual countries of emissions from international transport. Nevertheless, measures effective domestically are also applicable to international transport.

Selection of measures for analysis

BTCE (1995c) basecase projections showed that greenhouse emissions from trucks and LCVs would match those from cars by about the year 2015. Domestic aircraft emissions were also projected to grow rapidly, but with emissions from rail and sea transport remaining relatively unimportant. Although aspects of these projections were later revised, the choice of policy measures focused heavily on passenger and road freight vehicles, the two major sources of greenhouse emissions in the transport sector.

In selecting specific policy measures for analysis, the BTCE took account of several possible criteria. The overall aim was to select as comprehensive a range of measures as possible within the constraint of time and available analytical resources. Practicality of implementation was an important criterion in specifying details assumed for each of the measures. Potential policy measures were not chosen merely on the basis of likelihood of low cost of abatement.

Shifting intercapital freight from road to rail, accelerated introduction of technology, and a carbon tax, for example, were analysed because they are policy measures that are often suggested. Vehicle labelling was chosen because it can affect behaviour through the provision of information rather than through the price mechanism or by regulation. Road user charges in urban areas were selected because of the potentially significant gains from reducing costs due to traffic congestion and noxious emissions, as a spin-off social benefit. Tree planting was selected both because it reduces (net) emissions without the need to significantly modify travel behaviour, and because it provides a common point of comparison with likely costs in sectors other than transport. Analysis of the effects of resurfacing the National Highway System provided an opportunity to test the almost counter-intuitive proposition that emissions can be reduced by facilitating travel. There are also potential synergies between improvements to infrastructure and any revenue gained from measures such as parking charges or carbon taxes.

The BTCE chose to estimate marginal costs for a wide range of potential abatement measures despite early indications that some instruments were likely to be relatively expensive. A major reason for doing so was to increase public awareness of the likely costs of a number of popularly espoused measures such as scrapping older vehicles, or the compulsory tuning of cars. While some measures may appear intuitively to be obvious or preferable, detailed analysis of the alternatives is required to place them in policy perspective.

An unsuccessful attempt was made to estimate the costs of introducing a 'feebate' policy for new cars. Feebates involve the imposition of sales taxes (fees) on less fuel-efficient cars. Purchasers of smaller, more fuel-efficient cars would pay lower sales taxes or even receive a cash rebate from the government in the case of particularly fuel-efficient vehicles. Unfortunately the results were not entirely satisfactory because of the difficulty of determining accurately the average fuel efficiency of vehicle classes specified in the ITS/BTCE model, and the results are not recorded in this Report.

Overall, 16 measures were analysed in detail. Together they provide a good sample of possible policy measures, which is significantly greater than the number of instruments analysed in most comparable studies.

In deriving cost functions for the specific policy measures evaluated in the chapters below, the BTCE has sought as far as possible to isolate them from other potential measures. The possibility of interactions between policy instruments is explored in **chapter 19**.

Models used in the BTCE study

Five models were developed specifically for use in the BTCE Greenhouse Study, four of them in-house by BTCE researchers.

A number of conventional engineering models of urban traffic flows are available and can be used to model supply-side aspects of emissions (BTCE 1996d). However, little behavioural information has in the past been available to permit assessment of demand-side responses by individuals or households. To fill this gap, the BTCE commissioned Professor David Hensher, Director of the Institute of Transport Studies (ITS), University of Sydney, to construct a model of behavioural responses.

The ITS/BTCE model simulates urban travel behaviour in Canberra, Sydney, Melbourne, Brisbane, Adelaide and Perth. Household commuter travel behaviour is modelled using the major socioeconomic characteristics of households, the available vehicle fleets, housing, and transport. Relationships reflect a variety of effects, including income on housing choice and the effect of bus fares on commuter mode choice.

To determine these relationships, extensive travel behaviour surveys of households in the major Australian capital cities were carried out in 1994. The surveys covered both revealed preferences (actual, observed behaviour), and stated preferences (choices that survey respondents say that they would make under hypothetical circumstances in the future). Use of conjoint analysis to estimate travel decision relationships allows the model to analyse relationships outside current or historical bounds, such as the effect of introducing electric cars. Further detail on the ITS/BTCE model is provided in **appendix VI**, and in Hensher (1993).

A number of the policy measures analysed affect the volume of greenhouse gas emissions, principally through changes to the composition or size of the 'fleet' of cars, trucks or aircraft. Scrapping old vehicles or the accelerated introduction of emerging technologies, for example, will affect the relative mix of 'old' and 'new' vehicles, the average emission characteristics of the fleet, and the total number of vehicles. Because emission and fuel consumption characteristics are generally correlated with age, the in-house models developed by the BTCE are based on cohorts of vehicles of similar date of manufacture.

CARMOD was developed specifically to permit modelling of passenger vehicles. Refinements such as allowance for deterioration in fuel efficiency and emission performance as vehicles age, and increased emission rates in congested urban conditions, were designed to better represent actual 'on-road' operating conditions. Projections of basecase emissions for passenger vehicles published in BTCE (1995c, appendix VIII) have been revised on the basis of improvements to the model. **Appendix VII** provides further details of the CARMOD model.

Based on CARMOD, the BTCE model ENERGYMOD was designed specifically to evaluate the effects of fuel efficiency labelling of new cars **(chapter 8)**. It incorporates assumptions about proportions of new car buyers who switch to more fuel-efficient cars over time, and the costs involved in a labelling scheme.

A lack of suitable models of the road freight vehicle fleet led the BTCE to develop TRUCKMOD. It provides the capacity to investigate policy instruments that affect the aggregate road freight task, changes in the age composition of the fleet, total fuel usage, and total emissions produced. A fuller description of the model is provided in **appendix VIII**.

It was necessary for the BTCE to develop its own model of the aircraft fleet to permit analysis of the effect of new technology and other measures. AVMOD is an age-specific model constructed by the BTCE in an analogous manner to CARMOD and TRUCKMOD. Details are provided in **appendix IX**.

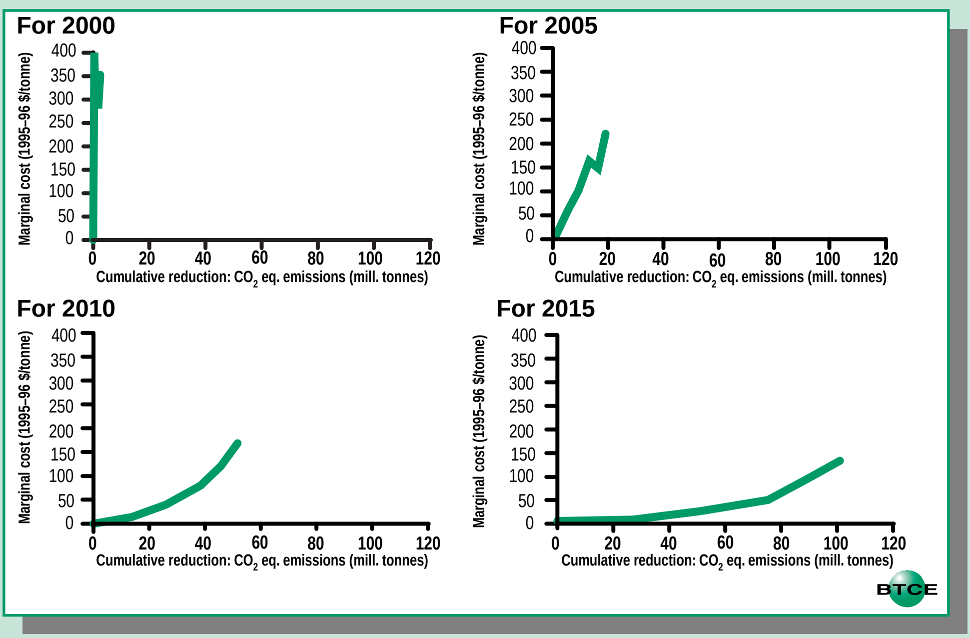
Estimation of costs and greenhouse emission reductions achievable from resurfacing national highways **(chapter 16)** was carried out using the BTCE's Road Infrastructure Assessment Model (RIAM) which incorporates a BTCE-modified version of the World Bank's Highway Development and Maintenance (HDM) model. RIAM was developed by the BTCE for work on national infrastructure issues, not specifically for the current Report.

...AT A GLANCE

Considerable scope exists for the accelerated introduction of more fuel-efficient cars. Penetration of the car fleet by such vehicles could reduce greenhouse gas emissions from the transport sector by up to 5 per cent over the period 1996 to 2015. The social cost is moderate, and would be lower but for the extra urban traffic congestion brought about by increased travel due to reduced fuel costs.

- Mandatory fuel efficiency standards for new cars are assumed to accelerate improvements in the fuel efficiency of the Australian passenger vehicle fleet through technological change. They are assumed to be introduced in stages from 1997. It is also assumed that a doubling in fuel efficiency results in an increase of 15 per cent in vehicle prices.
- Cumulative reductions in emissions of up to 100 million tonnes CO_2 equivalent are achievable over a period of 20 years.
- Reductions could be achieved in the longer term at a marginal cost of only $130 per tonne of CO_2 equivalent, or less. Costs are higher than those presented in BTCE (1996a, chapter 4) because allowance has been made for the costs of increased congestion due to additional travel (the so-called 'rebound effect') following savings by motorists on fuel costs.

FIGURE 3.1 FUEL SAVING TECHNOLOGY FOR CARS: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 3 ACCELERATED UPTAKE OF FUEL SAVING TECHNOLOGY IN NEW CARS

BACKGROUND

The average fuel intensity of the Australian passenger vehicle fleet has barely changed over two decades, hovering around 12 litres per 100 kilometres **(appendix II)**. Current trends in fuel consumption in new cars will reduce the fleet average fuel intensity only slowly over time.

A policy that increased new car fuel efficiency more rapidly would allow reductions in fuel consumption without vehicle owners having to alter their travel behaviour. Unlike instruments such as a carbon tax that would make travel more expensive, technology improvements can reduce the cost of operating a vehicle.

Prototype vehicles already in existence can achieve fuel efficiencies that are three times better than current levels by drawing on improvements in aerodynamics, engine performance and by reducing the mass of vehicles with lighter but stronger materials such as aluminium and lightweight steel. Considerable scope therefore exists to accelerate the introduction of fuel saving technology into the passenger vehicle fleet.

The province of Ontario in Canada operates a 'feebate' scheme, where purchasers of smaller, fuel-efficient vehicles obtain a rebate and purchasers of inefficient vehicles incur a fee (Ontario Ministry of Finance, pers. comm., 3 April 1995). However, because consumers are offered a choice, penetration of new technology vehicles into the fleet is likely to be relatively slow.

In the USA, under the 'corporate average fuel economy' (CAFE) scheme, the US government and car manufacturers coordinate research aimed at improving fuel efficiency standards averaged over all sales. The US government is considering a radical upgrade to the system that would see manufacturers aim for a tripling of CAFE fuel efficiencies (R. Sawyer, University of California, pers. comm. 3 November 1995).

In the absence of experience in Australia with schemes similar to those of Canada and the USA, it is difficult to estimate the rate at which the average fuel efficiency of the Australian fleet would change. For this reason the BTCE chose to analyse a policy instrument where the government sets a mandatory fuel efficiency standard for each class of new vehicle.

Nelson English, Loxton & Andrews Pty Ltd (1991a, p. 71) suggest that enforcing mandatory standards would be difficult but if the standards were comprehensive enough to avoid loopholes, the problems of non-compliance could be minimised. While some improvements could occur immediately, many would take some years to implement. The instrument analysed here therefore introduces relatively easy standards in 1996 and then lowers the mandatory fuel intensities annually until 2010. After 2010, fuel efficiency improvements occur at a rate equal to the basecase except where the limits of fuel efficiency have already been reached. The standards for 'snapshot' years are presented in table 3.1, and those for intermediate years are based on equal increments. Standards were set in terms of cycle test results (EPAV 1991, p. 21) rather than on-road conditions, which are thought to result in fuel intensities about 20 per cent higher than the cycle test.

Five intensity levels are specified in table 3.1, with the maximum technology scenario (MTS) envisaging fuel intensities for new cars to be half their 1995 values by 2010. The remaining four intensities are 20, 40, 60 and 80 per cent of the MTS.

TABLE 3.1 FUEL INTENSITY STANDARDS[a] FOR NEW CARS

(litres per 100 kilometres)

	Per cent of maximum technology scenario[b]				
Year	*20*	*40*	*60*	*80*	*100*
1995	8.8	8.8	8.8	8.8	8.8
2000	7.8	7.4	7.0	6.6	6.2
2005	7.1	6.3	5.5	5.3	5.1
2010	6.3	5.7	5.1	4.6	4.2
2015	5.1	5.2	4.8	4.3	3.8

a. On-road fuel intensities are about 20 per cent higher than the cycle test standards specified.

b. Maximum technology scenario is for new cars to be half their 1995 fuel intensity by 2010.

Sources BTCE estimates; DeCicco and Ross 1994, p. 34.

In estimating the effects of this measure, a different fuel intensity was used for each vehicle class. On the basis of the assumed MTS, the fuel intensity of large vehicles falls from 12 litres per 100 kilometres to 6 litres per 100 kilometres, and the fuel intensity of small vehicles falls to below 3 litres per 100 kilometres by 2015.

Vehicle classes are those specified in the ITS/BTCE household travel model **(appendix VI)** and include all sizes from micro to large, four-wheel drives, people movers, and LCVs used as substitutes for cars.

While the fuel efficiency standards were assumed to be mandatory, it was assumed that a government would not require specific technologies to be implemented. In the interests of economic efficiency, vehicle manufacturers would have the freedom to use the technologies that best suited their own processes and consumer demand.

METHODOLOGY

Two countervailing factors affect the potential reduction in greenhouse gas emissions from an accelerated introduction of fuel-efficient technology. Emissions will fall because of the reduced fuel consumption of new cars (the technology effect). But increased fuel efficiency will make travel cheaper and may induce additional travel (often called the 'rebound' effect). The overall change in emissions is the sum of these two effects. The BTCE CARMOD model **(appendix VII)** was the basis for the calculation of the technology effect. Changes in travel behaviour were derived from the ITS/BTCE model.

Marginal and total costs were derived from the resource costs involved in accelerating the introduction of new technology. These costs are the sum of: fuel costs, vehicle costs, administration costs, insurance, cost of additional travel, loss of fuel profits by wholesalers, health, accident and congestion costs.

A fall in fuel costs benefits owners of new technology vehicles. The fall in fuel costs is the fall in fuel consumption multiplied by the cost of fuel (74.2 cents per litre retail price in 1995–96, including 35 cents per litre resource cost). While consumers gain the full retail value of the fuel savings the government loses the excise revenue (39.2 cents). The net economic result is a saving to society equal to the resource cost of the fuel.

The most significant cost faced by consumers would be the cost of the technology improvements in new vehicles. To estimate these costs the BTCE derived a function relating vehicle price increases to fuel intensity reductions.

DeCicco and Ross (1994, p. 34) suggest that a 50 per cent decrease in fuel intensity would require only a 6 per cent increase in the price of vehicles. To ensure a conservative estimate, a function was chosen that gives an approximate 15 per cent increase in the price of vehicles for the 50 per cent decrease in fuel intensity. The function used is a cubic of the form:

$$\%\Delta\text{Price} = 0.088\%\Delta\text{FI} + 0.0006\%\Delta\text{FI}^2 + 0.00007\%\Delta\text{FI}^3$$

where $\%\Delta$Price is per cent increase in vehicle price, and $\%\Delta$FI is per cent decrease in fuel intensity.

Only the change in resource costs of the vehicles (excluding sales tax) was considered. However, vehicle purchasers face the retail cost of new technology embodied in vehicles, while the government collects the change in sales tax revenue that is based on wholesale prices. The vehicle price increase was also assumed to result in an increase in insurance costs equal to 4 per cent of the change in vehicle price.

In addition to the direct costs incurred by vehicle owners and the government there are other indirect costs. Vehicle owners gain consumer surplus from the additional travel induced by lower fuel costs. This gain was assumed equal to the increase in travel multiplied by half the fuel saving per kilometre. The loss of profits by petroleum producers due to reduced fuel sales was estimated at 2 per cent of the difference in retail fuel revenue (PSA 1995, p. 52 and Australian Institute of Petroleum Ltd, pers. comm. 20 February 1996).

Externality effects such as health, accidents and congestion also generate costs to the community.

Crash costs were estimated from vehicle-kilometres travelled (VKT); as travel increases so does the number of accidents. Environmental and accident costs are detailed in **appendix X**.

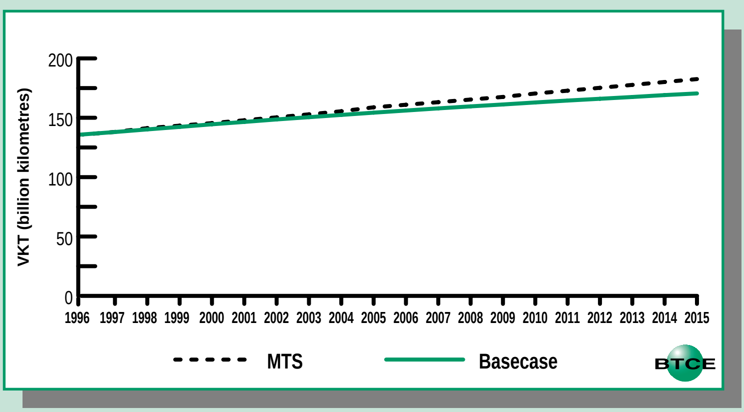
Congestion costs were derived on the basis of the ‘rebound’ effect. As the cost of fuel falls, total VKT will rise. If any additional travel is undertaken during peak traffic periods, then congestion costs will also rise. At times when roads are not congested the cost of travel does not rise. To account for changes in congestion costs, the BTCE assumed that the percentage increase in VKT during congested travel was half the percentage increase in overall travel. For example, if overall travel increased by 6 per cent then travel during congested times was assumed to increase by only 3 per cent. The BTCE also assumed that the amount of travel undertaken on congested roads increased, from the current level of 35 per cent of total travel to 40 per cent of total travel in 2015.

Mandatory standards would require enforcement as well as fuel intensity tests on all of the 200 to 300 new models entering the Australian market each year. The additional cost of testing one car in each vehicle type would be relatively small if fuel intensity testing were to be incorporated with the emissions testing program currently conducted on new vehicles. On the assumption that the additional cost is negligible it was not included in the analysis.

RESULTS

Total travel increases, because improved fuel efficiency makes travel less expensive once drivers have bought the new technology vehicles. Figure 3.2 shows the travel undertaken in both the basecase and the maximum technology scenario. By 2015 the difference between the basecase and the MTS is about 7 per cent in terms of VKT.

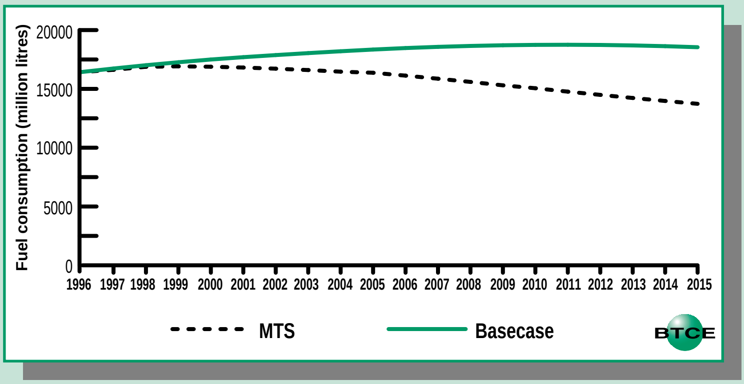
FIGURE 3.2 FUEL SAVING TECHNOLOGY FOR CARS: VEHICLE-KILOMETRES TRAVELLED FOR BASECASE AND MAXIMUM TECHNOLOGY SCENARIO



Source BTCE estimates.

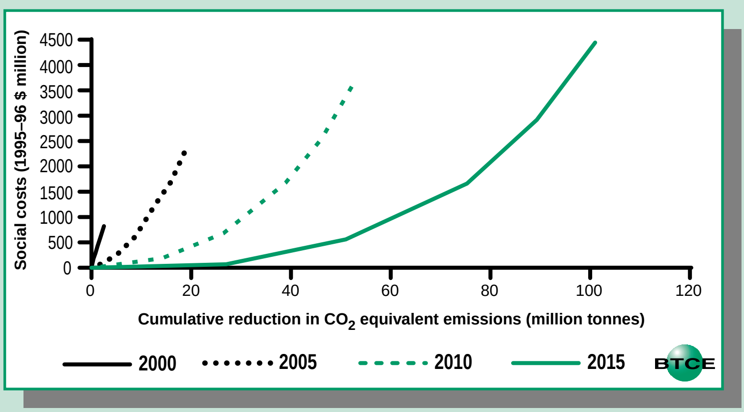
Despite the increase in travel, the volume of fuel consumed over the period from 1996 to 2015 would fall significantly (figure 3.3). The difference between the basecase and the MTS is small in early years but, as new vehicles penetrate the fleet, fuel consumption in the maximum technology scenario falls to 31 per cent below the basecase. For the MTS, fuel consumption in 2015 even falls below that of 1995, in spite of a 35 per cent increase in car travel over the 20 years.

FIGURE 3.3 FUEL SAVING TECHNOLOGY FOR CARS: FUEL CONSUMPTION FOR BASECASE AND MAXIMUM TECHNOLOGY SCENARIO



Source BTCE estimates.

FIGURE 3.4 TOTAL SOCIAL COSTS OF FUEL SAVING TECHNOLOGY FOR CARS, 2000, 2005, 2010 AND 2015



Source BTCE estimates.

Because fuel consumption falls, greenhouse gas emissions fall, particularly in the maximum technology scenario but also for the other intensity levels. Table 3.2 presents the cumulative CO_2 equivalent emission reductions compared with the basecase for each of the intensity levels in 'snapshot' years.

The marginal cost curves in figure 3.1 show that large improvements in emissions are achievable at relatively low cost, particularly by the year 2015 when over 90 per cent of the fleet is projected to consist of new technology vehicles. Marginal costs fall progressively from $311 per tonne in the maximum technology scenario in 2000 to below $130 per tonne in 2015. Marginal costs for the 20 and 40 per cent levels become very small over time, falling to $3 per tonne and $20 per tonne in 2015.

Table 3.3 summarises results for the 'snapshot' years.

Figure 3.4 shows total social costs for each of the snapshot years. For the 20 and 40 per cent intensity levels, total costs fall over time. This fall is caused by the dominance of fuel savings over the cost of new technologies in later years. In 1998, costs include the 1998 model new vehicles and the fuel savings from both the 1997 and 1998 models. In later years, most of the fleet would have the fuel saving technology and therefore generate fuel cost savings to owners while only people purchasing new vehicles in that year would experience the additional capital costs.

TABLE 3.2 CUMULATIVE DECREASE IN CO_2 EQUIVALENT EMISSIONS FROM FUEL SAVING TECHNOLOGY, FOR ALL CARS

(million tonnes)

Per cent of MTS[a]	*2000*	*2005*	*2010*	*2015*
20	0.4	4.5	13.7	27.0
40	0.8	8.3	26.0	51.0
60	1.2	12.2	38.4	75.3
80	1.8	15.4	45.7	89.3
100	2.5	18.1	51.7	101.0

a. Maximum technology scenario is for new cars to be half their 1995 fuel intensity by 2010.

Note Basecase emission levels for all cars are given in appendix III.

Source BTCE estimates.

TABLE 3.3 FUEL SAVING TECHNOLOGY FOR CARS: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1) Per cent of MTS[b]	*(2)* Cumulative reduction: CO_2 equivalent (million tonnes)	*(3)* Change in cumulative reduction: CO_2 equivalent (million tonnes)	*(4)* Social cost of cumulative reduction ($ million)	*(5)* Change in social cost ($ million)	*(6)* Average social cost[c] ($ per tonne)	*(7)* Marginal social cost[d] ($ per tonne)
1996 to 2000						
20	0.4	0.4	178	178	445	445
40	0.8	0.4	287	109	359	273
60	1.2	0.4	421	134	351	335
80	1.8	0.6	602	181	334	302
100	2.5	0.7	820	218	328	311
1996 to 2005						
20	4.5	4.5	245	245	54	54
40	8.3	3.8	614	369	74	97
60	12.2	3.9	1 232	618	101	158
80	15.4	3.2	1 687	455	110	142
100	18.1	2.7	2 262	575	125	213
1996 to 2010						
20	13.7	13.7	188	188	14	14
40	26.0	12.3	681	493	26	40
60	38.4	12.4	1 671	990	44	80
80	45.7	7.3	2 550	879	56	120
100	51.7	6.0	3 573	1 023	69	171
1996 to 2015						
20	27.0	27.0	69	69	3	3
40	51.0	24.0	560	491	11	20
60	75.3	24.3	1 662	1 102	22	45
80	89.3	14.0	2 919	1 257	33	90
100	101.0	11.7	4 444	1 525	44	130

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

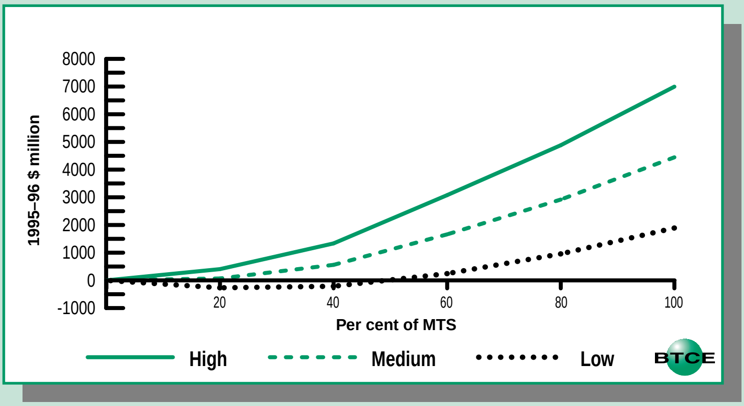
b. Maximum technology scenario is for new cars to be half their 1995 fuel intensity by 2010.

c. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates.

FIGURE 3.5 SENSITIVITY TO CHANGES IN CAR PRICE: TOTAL SOCIAL COSTS OF FUEL SAVING TECHNOLOGY FOR CARS IN 2015



Note 'Medium' refers to vehicle prices used in the analysis. 'Low' and 'high' refer respectively to prices 33 per cent below and above the medium level.
MTS = Maximum technology scenario

Source BTCE estimates.

Sensitivity testing

To test the sensitivity of the overall result to vehicle prices, costs were re-estimated with changes in vehicle prices 33 per cent above the original estimate and 33 per cent below the original estimate. While a rise in vehicle prices simply increased the magnitude of the costs, the 33 per cent decrease in vehicle prices resulted in negative costs at the 20 and 40 per cent intensity levels in the year 2015. Figure 3.5 shows the total costs for low, medium and high vehicle price in 2015.

Results were not disproportionately sensitive to changes in the discount rate.

EQUITY ISSUES

Consumers (vehicle owners) would experience gains from fuel cost savings and benefits due to the extra travel exceeding increases in the price of vehicles. This result suggests that it should not in fact be necessary to impose standards legislatively and that consumers should already be demanding fuel saving technologies from manufacturers.

But Lovins and Lovins (1995, p. 84) and Train (1985, p. 1249), although allowing for a wide range of discount rates, generally observe that vehicle owners have a high discount rate. That is, owners do not value future fuel cost savings highly enough to outweigh the additional capital costs required for vehicles to achieve mandatory standards.

The government (that is, taxpayers generally) would experience some loss of revenue because the loss in fuel excise would be likely to exceed any increase in sales tax revenue from more expensive new vehicles. Fuel production companies would lose revenue due to the fall in fuel consumption.

Increased VKT leads to large increases in congestion and accident costs. Health effects are negligible. Table 3.4 details the incidence of costs on consumers, producers, government and externalities.

TABLE 3.4 COMPOSITION OF TOTAL SOCIAL COSTS OF FUEL SAVING TECHNOLOGY FOR CARS, IN 2015

(1995–96 $ million)

	Per cent of maximum technology scenario[a]				
	20	*40*	*60*	*80*	*100*
Consumers (vehicle owners)	–1 730	–3 005	–3 564	–3 596	–3 309
Producers (fuel sellers)	50	98	146	176	202
Government	1 142	2 643	3 103	3 609	3 985
Externalities	607	1 304	1 978	2 730	3 566
Total	69	560	1 662	2 919	4 444

a. Maximum technology scenario is for new cars to be half their 1995 fuel intensity by 2010.

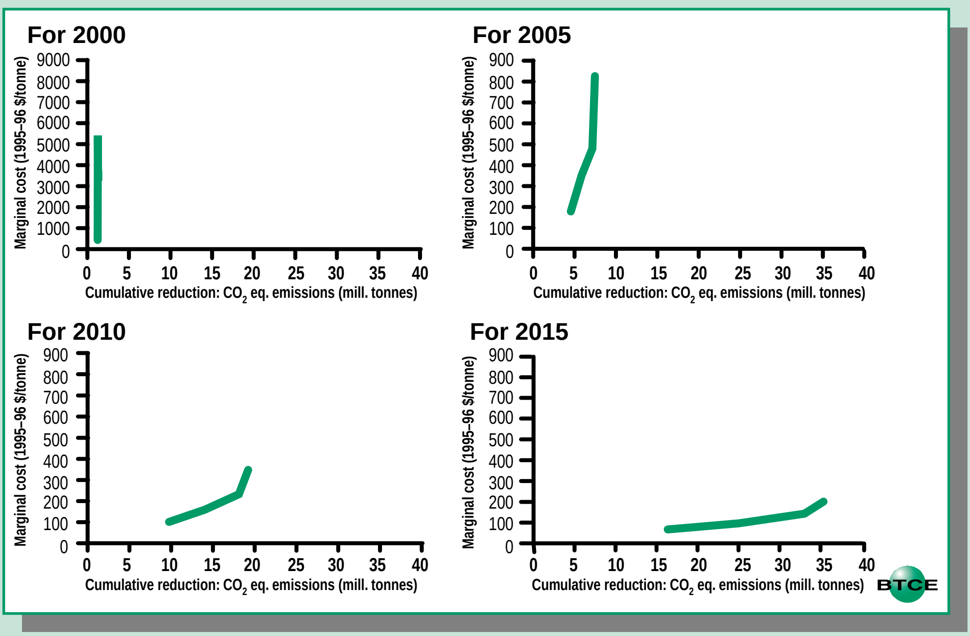
Source BTCE estimates.

...AT A GLANCE

Overall greenhouse gas levels can be reduced by controlling noxious, non-CO_2 emissions from cars. Introduction of four technologies to control emissions could reduce greenhouse gas levels from cars by up to 3.6 per cent over the period 1996 to 2015. Marginal costs would be very high in the short term, but low to moderate in 20 years time.

- CO_2 is the major emission (by mass) produced by passenger vehicles. But car exhaust emissions also include small amounts of the noxious gases carbon monoxide, nitrogen oxides, and non-methane volatile organic compounds. Many of these noxious emissions are also much more potent greenhouse gases than CO_2 itself.
- Controlling noxious emissions can reduce health costs to the community, as well as reducing overall greenhouse gas emissions.
- Four emission control technologies were considered: replacement of the catalyst in catalytic converters every eight years, reduction of evaporative losses of fuel during engine operation, tighter exhaust emission standards for new cars, and installation of catalyst warm-up converters to reduce cold start emissions.
- New car buyers would initially bear most of the cost of new technology, but it would be passed on to subsequent used car buyers.

FIGURE 4.1 CAR EMISSION CONTROL TECHNOLOGY: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Note y-scales do not match.

Source BTCE estimates.

CHAPTER 4 INCREASED UPTAKE OF EMISSION CONTROL TECHNOLOGY IN NEW CARS

In terms of mass, carbon dioxide (CO_2) is the major greenhouse gas emitted by motor vehicles. However, other gases emitted by passenger vehicles, including methane (CH_4), non-methane volatile organic compounds(NMVOCs), nitrous oxide (N_2O), other nitrogen oxides (NO_x) and carbon monoxide (CO), generally have higher global warming potentials (GWPs). For example, over a 100-year time horizon, methane has over 20 times the warming effect of an equal mass of CO_2 **(appendix table IV.1)**.

Whereas reductions in CO_2 are more directly achievable through increased fuel efficiency, noxious emissions are more easily controlled through specific emission technologies. Four technological possibilities are examined below.

Catalyst replacement

The efficiency of catalytic converters in reducing exhaust emissions of CO, hydrocarbons (HCs) and NO_x deteriorates over time. Catalysts gradually deactivate during vehicle use, especially if there are significant levels of impurities such as lead or sulphur in the fuel or air.

Deterioration rates based on FORS (1995), Watson (1993), EPA (1995) and Carnovale et al. (1991) for the emission performance of catalytically controlled Australian vehicles are given in BTCE (1996a, table 2.5). The magnitudes of the deterioration rates imply that, after eight to ten years, emission levels for vehicles fitted with catalysts are on average similar to vehicles that are well maintained but without a catalyst (and otherwise equivalent).

It has been assumed that the government requires from 1997 onwards that all catalytically controlled Australian cars must have their catalyst replaced every eight years. On this basis, all catalyst vehicles eight years of age or older in 1997 would have their catalyst replaced in that year. In each following year, replacements would be made for any vehicles that have not had the contents of their catalytic converter renewed for at least eight years.

Reduced running losses

About half of total NMVOC emissions from cars are due to evaporative HC losses. Evaporative emissions result from running losses, hot soak losses, diurnal losses and crankcase ventilation (for pre-1970 vehicles). Until recent years, running losses were not typically included in Australian emission inventories. As Carnovale et al. (1991, p. 51) record, running losses, or evaporative emissions released during engine operation, were believed to be nearly zero because the existing evaporative emission control systems were designed to pass the petrol generated during this period directly into the running engine.

However, tests by the USEPA (1990, 1993) have shown that running losses are probably not negligible. Under certain circumstances they can even be the major contributor to vehicle HC emissions. Running losses have been shown to rise with increasing ambient temperature, increasing fuel vapour pressure (volatility) and decreasing vehicle speed (USEPA 1990). For vehicles using high vapour pressure fuel under hot conditions, running losses can account for around 40 per cent of total HC emissions (Carnovale et al. 1991, p. 53).

The USEPA (1990, p. 83) found that late model vehicles have average running losses of less than 0.2 g/km when using a standard test fuel of similar vapour pressure to petrol sold in the USA. However, the vapour pressure of the standard US test fuel is significantly below that typical for petrol sold in Australia. USEPA tests on vehicles using fuel with a vapour pressure more representative of Australian petrol yielded much higher running losses, of the order of 1.1 g/km (USEPA 1990, p. 83).

Accurate measurements of running losses have not yet been made in Australia. Overseas studies have found that running losses vary considerably between vehicles, but it has not been determined whether the losses depend on any particular vehicle characteristics (Morgan et al. 1993; USEPA 1990, 1993). Since the exact causes and magnitudes of running losses have not been identified, the derivation of greenhouse abatement costs is necessarily rather speculative. Although estimates of costs are therefore very approximate, the limited data available imply that running losses could be a significant source of emissions and that more research into their detection and reduction is warranted.

Because of the uncertainties associated with running losses, it has been assumed for the purposes of the analysis that their reduction would require further investment in vehicle emission testing facilities and the fitting of on-board diagnostics (OBD) to new cars (to monitor emission performance). It has also been assumed that such measures, combined with the requisite vehicle fuel system engineering, would be capable of reducing running losses for new vehicles manufactured after the year 2000 from the assumed basecase value of 1 g/km to 0.16 g/km (the level assumed for other evaporative emissions from such vehicles).

Lowering the average vapour pressure of Australian fuel would probably reduce running losses significantly. However, it has been assumed that fuel specifications are fixed, and that emission reductions are achieved purely through vehicle engineering.

By focusing on running loss reductions, it is likely that simulated emission reductions may have been overestimated because future improvements in engine management systems could serve to decrease running losses. However, the costs could also have been overstated, because OBD may not be required to reduce running losses. If OBD were not included as part of a policy to reduce running losses, calculated costs for the new design standards (see below) would have to increase. OBD could also have further benefits because they would significantly assist any inspection and maintenance campaigns for in-service vehicles.

New design standards

The basecase incorporates the revisions to the Australian Design Rules (ADRs) for new vehicles which are scheduled to be introduced from 1997 to reduce levels of noxious emissions **(table VII.1)**. In the basecase, these standards are maintained throughout the projection period. As part of the emission technology measure being evaluated in this chapter, it is assumed that the government will require a further tightening of emission standards in 2000.

It has also been assumed that the average exhaust emission rates of new cars manufactured after the year 2000 can be reduced by approximately 40 per cent by increasing the penetration rate of already known technologies (following Touche Ross 1995). The scenario assumes that emission standards of 1.5 g/km for CO (down from 2.1 g/km), 0.17 g/km for HC (down from 0.26 g/km)and 0.14 g/km for NO_x (down from 0.63 g/km) can be imposed in 2000. The emission standards assumed are roughly equivalent to the Ultra-low Emission Vehicle (ULEV) standard specified by the California Air Resources Board (CARB).

It is envisaged that car manufacturers would be able to use a combination of individual technologies to meet the revised emission standards. The design packages could include improved electronic engine control and exhaust gas recirculation (aided by the OBD engine system monitoring to reduce running losses), improved fuel preparation and injection, higher catalyst volumes or improved engine materials.

Heated catalysts

Catalytic converters have practically no effect on emissions when the engine and converter are cold. To function correctly, the catalyst must reach its operating temperature. This typically takes the first two to three minutes of a journey. During these initial minutes of engine operation, emission levels for catalytically controlled vehicles are around 15 times those when the engine is hot (Bendtsen & Thorsen 1994, p. 7).

One of the potential technologies available to reduce cold start emissions relies on a heater to bring the catalyst to operating temperature as soon as possible. A variety of catalyst warm-up systems is being developed, some electrically heated and others using vehicle fuel in small burners.

Effects on fuel consumption

The technologies evaluated in this chapter assume changes solely to basecase emission rates and not to basecase fuel efficiency. That is, reductions in non-CO_2 vehicle emissions are not made at the expense of increases in average fuel consumption (and consequent increases in CO_2 emissions). It is assumed that if any emission control technologies cause a slight fuel consumption penalty, then manufacturers will engineer other elements of the vehicle design to compensate (for example, by reducing vehicle weight).

Of the technologies assessed, catalyst heaters would be the most difficult to introduce without increasing fuel consumption. There are also some doubts about the long-term use of catalyst heaters, with the effective lifetime of the catalyst possibly being reduced.

METHODOLOGY

In the model, incremental reductions in greenhouse gas emissions from passenger vehicles are achieved through the sequential introduction of four technologies. These technologies essentially represent varying degrees of intensity of application of an emission control policy measure.

- The first level of intensity involves the mandatory replacement of catalysts every eight years, for all vehicles equipped with a catalytic converter;
- The second level of intensity involves catalyst replacement plus the requirement that new cars be engineered so as to reduce running losses;
- The third intensity level requires the introduction of new vehicle design standards in the year 2000, so that emission performance improves for all noxious gases;
- The fourth intensity level requires catalyst replacement, reduced running losses, new design standards, and the fitting of catalyst warm-up converters to reduce cold start emissions.

Costs for various emission control technologies were derived from data presented in a report to the European Commission on reducing emissions from road vehicles (Touche Ross 1995). For a variety of emission abatement measures, Touche Ross identified the likely incremental costs due to implementing the measures, including:

- research and development of vehicles and emission control systems,
- investment costs (for improvements in production and testing facilities);
- administrative and regulatory costs associated with monitoring or enforcement;
- new vehicle components; and
- production overheads such as additional labour costs.

Touche Ross surveyed European vehicle manufacturers to ascertain the costs of achieving reductions in vehicle pollution using emission control technology. The survey covered available technologies and those currently in development. Manufacturers were asked to provide costs for technology design packages that could be fully incorporated into vehicle production runs by 2000. Touche Ross reported all costs in terms of 1996 European Currency Units (ECU), which were converted using an exchange rate of A$1.6 per ECU.

In line with the assumption that the emission control technology packages would not increase projected fuel consumption trends, Touche Ross (1995, p. 115) found that 'on average across all manufacturers and all categories of vehicle there was an almost negligible fuel consumption increase of less than 0.2 per cent' after incorporating all the new components into vehicle designs.

The following assumptions were made in estimating incremental costs:

- The average cost of catalyst replacement is $250. Touche Ross (1995, p. 180) derives an average cost of repair of 155 ECU for a catalyst equipped car that has suffered failure of CO, HC or NO_x control systems.
- The incremental cost of implementing the second intensity level, replacement of catalysts plus reduction of running losses, is assumed to be $300 per new vehicle manufactured after 2000. Touche Ross has estimated the average costs of fitting on-board diagnostics as about 97 ECU per vehicle (Touche Ross 1995, p. 190) and of the proposed European evaporative systems as about 49 ECU per vehicle (Touche Ross 1995, Annexe II). The sum of these amounts (146 ECU) does not include costs for fitting on-board vapour recovery systems to vehicles (Touche Ross 1995, p. 109) or for providing additional equipment to vehicle testing stations to allow dynamometer measurement of running losses (Touche Ross 1995, p. 176). Since such measures could be required, to significantly reduce running losses, the estimates have been scaled up by around 25 per cent to allow for their inclusion. The assumed cost ($300) is very uncertain, especially since it has not yet been determined which technical procedures are fully effective in the abatement of running losses.
- The incremental cost of implementing the third intensity level, level 2 plus new vehicle design standards, is assumed to be $410 per new vehicle manufactured after 2000. Touche Ross has derived costs associated with introducing technology packages to reduce average emission rates of new cars by about 40 per cent. Averaging across results for different vehicle classes gives an estimate of around 256 ECU per vehicle (Touche Ross 1995, Annexe I, p. 255) to meet emission standards equivalent to those proposed in this study (1.5 g/km for CO, 0.17 g/km for HC and 0.14 g/km for NO_x from the year 2000).
- The cost of the fourth level, level 3 plus catalyst heaters in new cars after 2000, is assumed to be $190 per vehicle. The $190 value is an

incremental cost, composed of the cost of providing the new component (the heater) minus the cost of components required under the second intensity level that are superseded by catalyst heaters. Touche Ross (1995, p. 92) had included the fitting of close-coupled catalyst systems at an average cost across vehicle classes of 60 ECU per vehicle. Close-coupling the catalyst means fitting the catalytic converter so that the catalyst is close to the exhaust manifold, where the heat generated speeds up the attainment of the catalyst's operating temperature. However, it is assumed that close-coupling is not needed if catalyst heaters are fitted. Using an average cost for catalyst heaters of 179 ECU per vehicle (Touche Ross 1995, Annexe I), results in an estimated incremental cost of 119 ECU per vehicle in the absence of close-coupling.

Externality effects were taken into account in the analysis. Approximate unit damage costs (dollars per kilogram of gas emitted) were derived by reviewing the literature **(appendix X)**. Estimated damage costs, which relate primarily to health losses caused by air pollution, should only be treated as likely order of magnitude values. The difficulty of estimating such costs leads to a wide variation in the results of the different studies reported in the literature.

Environmental damage costs have been estimated in this chapter using average unit costs of $0.05/kg for HC and NO_x emissions and $0.001/kg for CO emissions **(appendix X)**. Benefits due to reductions in air pollution through the various emission technology options can be assessed roughly by combining these unit cost estimates with the emission estimates from the CARMOD model **(appendix VII)**.

Costs (including offsetting benefits of reductions in noxious emissions) have been cumulated in order to match the cumulative effects of emission reductions achieved through the introduction of the four technologies. Marginal costs for the years presented (2000, 2005, 2010 and 2015) are 'snapshots' which take into account all costs incurred in previous years in order to achieve estimated emission reductions in the 'snapshot' year. To permit comparisons between years and with other potential policy measures, all costs for 1996 to 2015 have been presented in 1996 values using a 10 per cent discount rate.

RESULTS

Results for greenhouse gas emission reductions in 'snapshot' years are presented in table 4.1. At the highest intensity level, total greenhouse emissions (CO_2 plus non-CO_2) are reduced from basecase levels by

3.6 per cent of the cumulated CO_2 equivalent emissions over the period 1996 to 2015. The reduction in total greenhouse gas emissions in 2015 itself is more than 7 per cent of the basecase emissions for that year (figure 4.2).

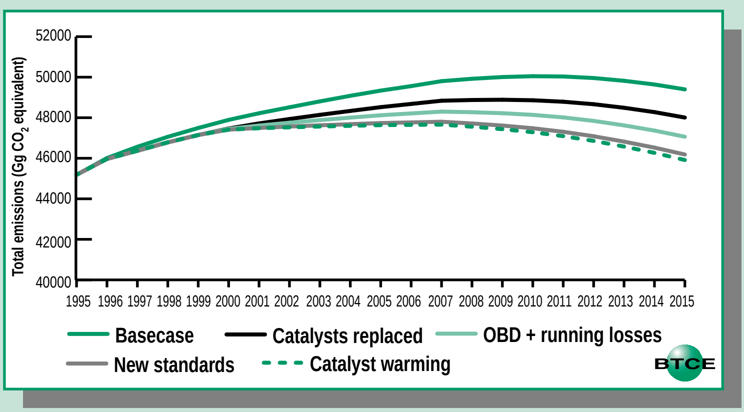
Reductions in annual tonnages of noxious emissions alone (table 4.2) increase steadily up to 2015. Noxious emissions in CO_2 equivalents for 2015 are over 40 per cent lower than the basecase in that year. Over the period 1996 to 2015, cumulative non-CO_2 emissions (in CO_2 equivalents) fall by 24 per cent compared to the basecase (figure 4.3).

Costs

The pollution control equipment required to implement emission control at the highest intensity level would cost about 3 per cent of the average purchase price of $30 000 for a new car in 1996. It would thus cost car owners about $0.5 billion per year. Inclusion of the health benefits due to lessening air pollution reduces the total social cost, on average, by about 1.5 per cent.

At the highest intensity level, the net present value of the total social cost cumulated over the period 1996 to 2015 of all the emission technology is estimated at about $3.6 billion (table 4.1). Marginal costs are given for 'snapshot' years in table 4.1, and the results for 2015 are illustrated in figure 4.4.

FIGURE 4.2 PROJECTED TOTAL GREENHOUSE GAS EMISSION LEVELS FOR BASECASE AND CAR EMISSION CONTROL TECHNOLOGY SCENARIOS



OBD On-board diagnostics

Source BTCE estimates.

TABLE 4.1 CAR EMISSION CONTROL TECHNOLOGY: SOCIAL COSTS[a] OF REDUCTION IN EMISSIONS CUMULATED FROM 1996

(1) Intensity[b]	(2) Cumulative reduction: CO_2 equivalent	(3) Change in cumulative reduction: CO_2 equivalent	(4) Social cost of cumulative reduction	(5) Change in social cost	(6) Average social cost[c]	(7) Marginal social cost[d]
(per cent)	*(million tonnes)*	*(million tonnes)*	*($ million)*	*($ million)*	*($ per tonne)*	*($ per tonne)*
1996 to 2000						
1	1.243	1.243	542	542	436	436
2	1.261	0.018	635	93	504	5 167
3	1.300	0.039	764	129	588	3 308
4	1.314	0.014	816	52	621	3 714
1996 to 2005						
1	4.551	4.551	813	813	179	179
2	5.845	1.294	1 266	453	217	350
3	7.155	1.310	1 895	629	265	480
4	7.463	0.308	2 149	254	288	825
1996 to 2010						
1	9.750	9.750	986	986	101	101
2	14.036	4.286	1 669	683	119	159
3	18.112	4.076	2 617	948	145	233
4	19.218	1.106	3 002	385	156	348
1996 to 2015						
1	16.371	16.371	1 098	1 098	67	67
2	24.978	8.607	1 927	829	77	96
3	33.042	8.064	3 081	1 154	93	143
4	35.368	2.326	3 550	469	100	202

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. Intensity level 1 = catalysts replaced every 8 years. Level 2 = level 1 + on-board diagnostics to reduce running losses. Level 3 = level 2 + tighter design standards for new vehicles. Level 4 = level 3 + catalyst warm-up systems.

c. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates.

TABLE 4.2 REDUCTIONS IN NOXIOUS EMISSIONS FROM ACCELERATED UPTAKE OF EMISSION CONTROL TECHNOLOGY FOR CARS

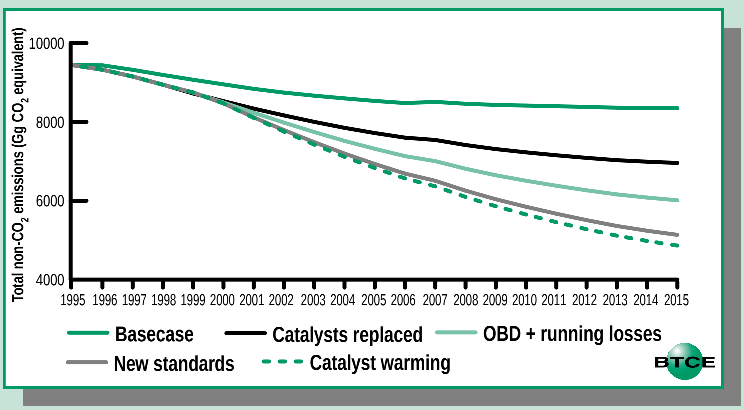
(gigagrams of gas)

	Year			
Gas, intensity[a]	*2000*	*2005*	*2010*	*2015*
CO				
1	265.0	486.0	695.0	804.0
2	265.0	486.0	695.0	804.0
3	270.0	528.0	771.0	906.0
4	270.0	574.0	860.0	1 029.0
NO_x				
1	9.1	19.2	27.7	32.6
2	9.1	19.2	27.7	32.6
3	12.4	50.9	81.4	103.9
4	12.4	51.5	82.6	106.0
HC				
1	8.1	20.4	33.8	40.6
2	13.1	72.1	123.9	158.9
3	13.9	79.7	137.4	177.0
4	13.9	83.8	145.0	188.0

a. Intensity level 1 = catalysts replaced every eight years. Level 2 = level 1 + on-board diagnostics to reduce running losses. Level 3 = level 2 + tighter design standards for new vehicles. Level 4 = level 3 + catalyst warm-up systems.

Source BTCE estimates.

FIGURE 4.3 PROJECTED NON-CO_2 GREENHOUSE GAS EMISSION LEVELS FOR BASECASE AND CAR EMISSION CONTROL TECHNOLOGY SCENARIOS



OBD On-board diagnostics

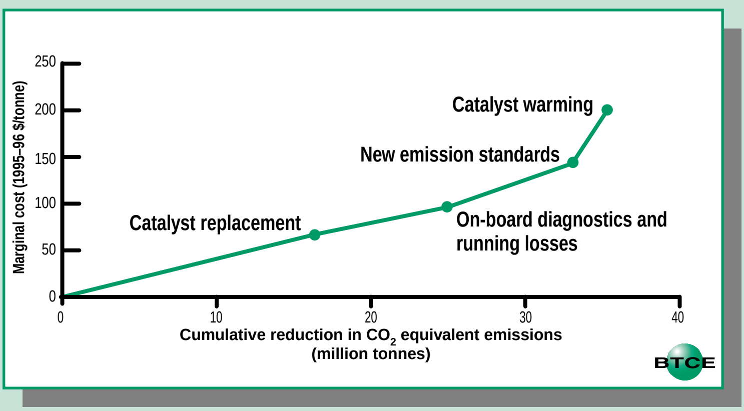
Source BTCE estimates.

Sensitivity testing

A discount rate of 10 per cent was applied to obtain present values (1995–96 $) of all costs. To test the sensitivity of the results to the discount rate, marginal costs were re-estimated using rates of 5 and 15 per cent. A higher discount rate results in a lower net present value of the stream of costs, and therefore a lower cost per tonne of emission reduction. The resulting changes to the cost estimates were roughly proportional to the changes in the discount rate, with a 50 per cent decrease in the discount rate causing the marginal costs to rise by around 60 per cent, and a 50 per cent increase in the discount rate causing the marginal costs to fall by around 40 per cent.

The results also depend on the costs assumed for equipping passenger vehicles with the different technologies. Although Touche Ross (1995, p. 17) considered it 'unlikely that retail vehicle prices would increase by more than 5 per cent under the most stringent emissions reduction scenario', the most stringent scenario in Touche Ross (1995) involves emission reductions considerably below those assumed in this chapter.

FIGURE 4.4 MARGINAL SOCIAL COSTS IN 2015 OF INTRODUCING CAR EMISSION CONTROL TECHNOLOGIES



Source BTCE estimates.

EQUITY ISSUES

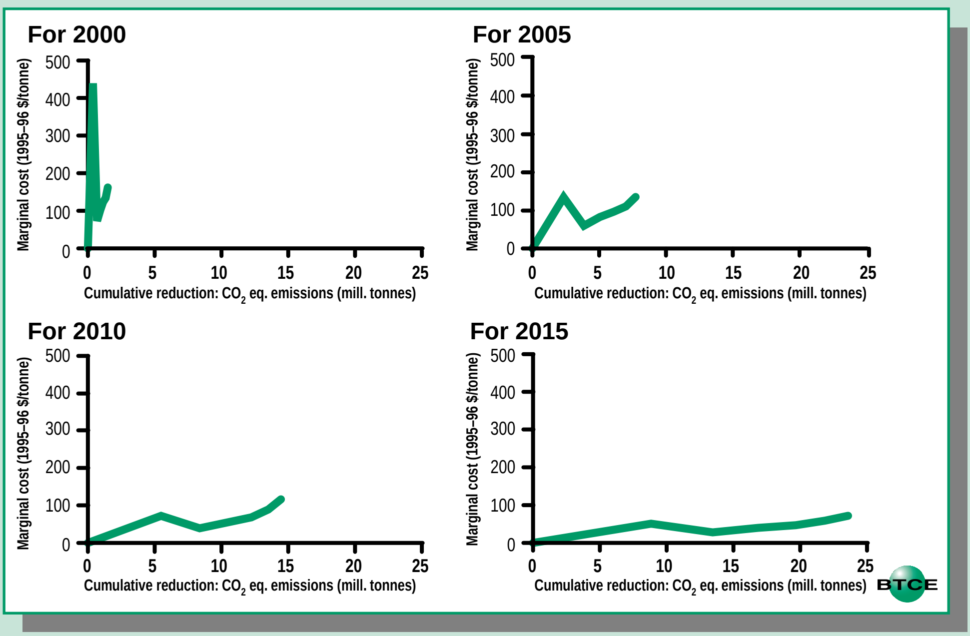
The costs of requiring emission control technologies would fall primarily on car buyers. New car buyers would initially bear most of the additional cost, but it would be passed on to subsequent used car buyers through higher vehicle prices. Higher prices might well encourage people on lower incomes to hold on to their older vehicles for longer periods.

...AT A GLANCE

Reductions in greenhouse emissions can be achieved through targeted scrapping of older, fuel-inefficient cars. Their replacement with newer vehicles would reduce both fuel consumption (and hence CO_2) and noxious emissions. A cumulative reduction of about 20 million tonnes of greenhouse gas emissions (about 2 per cent of basecase car emissions) is achievable by 2015 at a marginal cost below $100 per tonne of CO_2 equivalent.

- Cars that emit high levels of noxious gases such as carbon monoxide also tend to have somewhat higher fuel consumption.
- A small number of cars may be responsible for a disproportionate share of pollutant emissions. If these vehicles could be identified, governments could offer to buy them for scrapping. The higher the government offer price, the greater the number of vehicles likely to be scrapped.
- Inexpensive remote sensing of tailpipe emissions was assumed to be used to identify gross polluting vehicles.

FIGURE 5.1 CAR SCRAPPING: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 5 ACCELERATED SCRAPPING OF OLDER CARS

A 'cash for clunkers' policy can be used to reduce greenhouse gas emissions by replacing older, particularly fuel-inefficient cars with newer ones. The term 'clunker' is American; 'clapped out' is the nearest Australian equivalent.

Under a 'cash for clunkers' policy, the government would each year identify cars which are particularly fuel- and emissions-inefficient, make offers to buy them, and scrap those that it succeeds in buying.

The number of clunkers removed from the road each year can be increased by raising the level of the offer price for targeted vehicles. Higher offer prices increase the number of acceptances, but at an escalating cost.

For successful application of a scrapping measure, a way is needed to target inefficient cars (the ones that use large amounts of fuel), as well as those that would be least expensive for the government to buy. Such targeting would ensure the best cost–benefit ratio in purchases.

Two criteria are assumed to be used in targeting 'clunkers': age and level of pollutant emissions.

The criterion of age was taken in this chapter to be that all cars 13 years of age and over are eligible for purchase. Older model cars are generally the least expensive. In addition, the older model cars tend to have generally higher fuel consumption as well as higher emissions of NMVOCs and non-CO_2 greenhouse gases (FORS 1996, pp. 37 & 52 and CDROM database).

Emission levels of non-CO_2 gases is the second criterion for targeting. A recent study has found that there is a general correlation between the emission of pollutants and the degree of deterioration in the fuel efficiency of the engine as cars age (FORS 1996, CDROM database). The emissions criterion takes advantage of this correlation to target the particularly fuel- and emissions-inefficient vehicles.

It was assumed that the method of measuring emissions would involve a system such as remote roadside sensing of tailpipe emissions as cars drive by, coupled with photographic equipment to record registration numbers. Remote sensing allows identification of inefficient vehicles in the least expensive method possible.

Remote sensing equipment currently available has a fairly reliable level of measurement accuracy, but does involve a certain proportion of false readings (Touche Ross 1995, pp. 158–161). As such it is as yet unsuitable for mass enforcement, unless additional facilities are built to rigorously test failed vehicles. In the 'cash for clunkers' measure analysed in this chapter, remote sensing is assumed to be used only for targeting, not for enforcement of emission standards.

METHODOLOGY

It was assumed that for every car sold to the government, a replacement vehicle is ultimately obtained (either through purchase of new vehicles or reduced scrapping of used ones). That is, it has been assumed that the desired fleet size for Australia as a whole is unaffected in any year. This assumption may in fact result in a conservative estimate of the reduction in emissions. Evidence from the USA suggests that, having accepted cash for their cars, some people subsequently revert to using other family cars or public transport (Alberini, Edelstein et al. 1994, pp. 71–72).

The sellers of clunkers who use the money to buy a replacement vehicle are presumed to trade up to a more recent model or to buy a new car. Total annual vehicle kilometres travelled were assumed to remain unchanged from basecase projections.

Reductions in greenhouse gas emissions

Expected emission reductions were determined using BTCE CARMOD **(appendix VII)**, making use of the options for selection of high emission vehicles and for increasing the scrapping rate of older vehicles.

In calculating the emissions benefit of a potential scrapping policy, the low expected remaining lifetime of the clunkers is taken into account in the model through the scrapping function. However, there is some evidence that the cars turned in for scrapping have even lower expected lifetimes than the average vehicle of that age (Alberini, Edelstein et al. 1994, p. 65).

The car scrapping measure assumes that roadside testing is used to identify high-polluting vehicles. But studies have shown that the vehicles so identified tend to have higher fuel consumption, even when differences in age are taken into account (based on BTCE analysis of FORS 1996 CDROM database). Thus in simulating the use of roadside sensing of tailpipe emissions, the CARMOD option for selecting high emitters was run using the assumption that identified high emitting vehicles had emission rates of non-CO_2 gases 3 times that of an average vehicle of the same age and used 20 per cent more fuel than the average for the same vintage of vehicle.

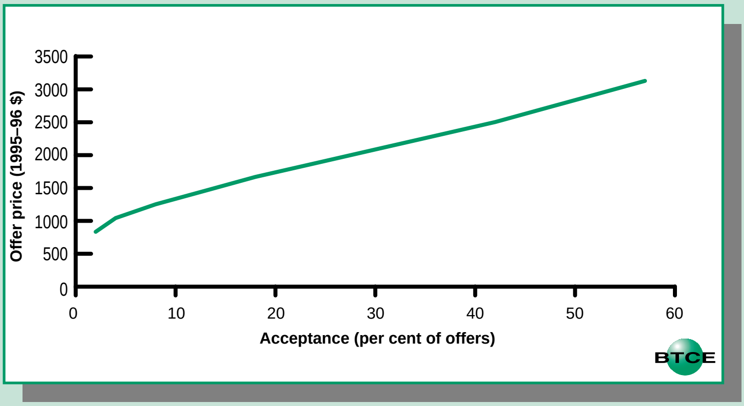
Numbers of vehicles scrapped were assumed to increase as the offer price increased. The assumed relationship between offer price and acceptance is given in table 5.1 and figure 5.2. It was specified by drawing on data from a US 'cash for clunkers' program (Alberini, Edelstein et al. 1994, p. 59; Alberini, Edelstein & McConnell 1994, p. 14) but reflecting Australian vehicle prices. The acceptance level shown refers to the proportion of owners with vehicles over 13 years old that would accept the stated offer price. Table 5.2 shows the offer price levels analysed in this study and the increased scrapping rates (as a percentage of the whole fleet) assumed to result from these offers.

TABLE 5.1 CAR SCRAPPING: ASSUMED VEHICLE PURCHASE ACCEPTANCES BASED ON OFFER PRICE

Offer price (1995–96 $)	*Acceptance (per cent of offers)*
$834	2
$1043	4
$1252	8
$1460	13
$1669	18
$1877	24
$2086	30
$2294	36
$2503	42
$2712	47
$2920	52
$3129	57

Source BTCE estimates based on Alberini, Edelstein et al. 1994.

FIGURE 5.2 CAR SCRAPPING ACCEPTANCE BASED ON OFFER PRICE



Source BTCE estimates.

TABLE 5.2 OFFER PRICES AND CAR SCRAPPING RATES

Offer price (1995–96 $)	*Acceptance (per cent of offers)*	*Extra scrappage (per cent of total fleet)*
$893	2.5	0.2
$1082	5.0	0.4
$1223	7.5	0.6
$1338	10.0	0.7
$1447	12.5	0.9
$1545	15.0	1.0

Source BTCE estimates.

Replacement vehicles come from two sources—purchases of new cars and reduced scrapping of used ones. It was assumed arbitrarily that, as the offer price and scrapping of clunkers increases, the proportion of replacement vehicles coming from new car purchases rises—from 4.5 per cent when 1 per cent of cars 13 years and older are scrapped, to 25 per cent when 6 per cent of the older cars are scrapped per year.

Costs

Motorists (consumers) benefit from owning cars that use less petrol. Purchases and sales of vehicles within the replacement chain balance out as far as fuel use is concerned, leaving the net difference being that between the scrapped car and the new replacement vehicle. BTCE CARMOD measures the difference in overall fleet fuel use, and the saving to motorists was estimated using the 1995–96 retail petrol price of 74.2 cents per litre. Costs of replacement vehicles were assumed to be balanced by the stream of benefits that the use of these vehicles is expected to generate over time.

Payments received from government for old cars represent a benefit to their erstwhile owners, but are partially balanced by the loss of the services of the car turned over for scrapping (assumed to be less than the average subsidy necessary to obtain the marginal acceptance of offer—see Alberini, Edelstein et al. 1994, p. 31).

Producers (in this case the oil companies) bear a cost in lost profits on fuel sales. This loss was assumed equal to 2 per cent of the retail price of the fuel saved (PSA 1995, p. 52 and BTCE estimates).

A government scrapping scheme would incur costs for testing and administration, as well as result in changes in tax revenues. Remote sensing units were assumed to cost $200 000 each and to last five years (FORS, pers. comm., October 1995). Technicians required to maintain them were costed at $20 per hour and 156 hours per year per unit (Touche Ross 1995, p. 183). Each unit can test about 1000 vehicles a day (Touche Ross 1995, p. 182) or about 200 000 vehicles a year. If it is assumed that only 75 per cent of the vehicle stock is tested in any one year (because of limitations in rural coverage), 30 to 40 remote sensing units would be required for Australia as a whole.

A once-off start-up cost of $2 million for setting up the administration of the emission testing program was assumed. Thereafter, government administration costs were calculated on the basis of $5 per test, and include all the processing of the tests, offers and purchases (Touche Ross 1995, p. 183). Payments made to purchase cars (any residual scrapping value of the cars is ignored) also involve direct outlays.

Government revenue changes involve a loss of fuel excise taxes and tax receipts from oil company profit taxes.

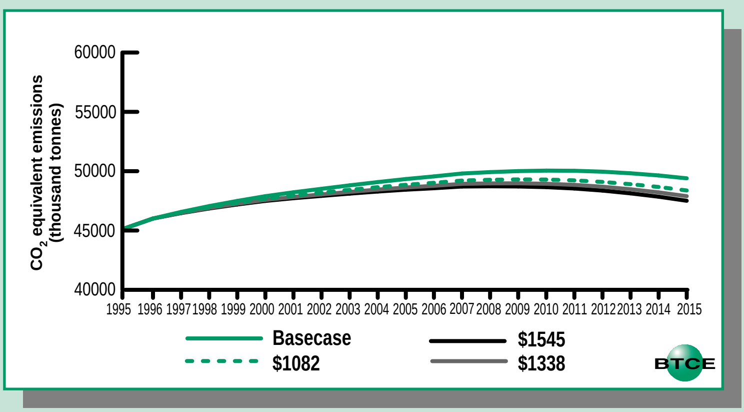
Reductions in noxious emissions through newer, more fuel- and emissions-efficient cars replacing the most polluting older vehicles are the main (positive) externalities that would be generated by a car scrapping measure. Urban and non-urban environmental benefits given in **appendix X** were used to value the reductions in pollutants estimated using BTCE CARMOD.

RESULTS

The greenhouse benefits of the car scrapping measure are limited to a 1–5 per cent reduction in cumulative emissions between 1996 and 2015. There is a fairly quick reduction in CO_2 equivalent emissions through to 2005 and a consistent reduction over the basecase thereafter (figure 5.3). Table 5.3 shows decreases in cumulative greenhouse gas emissions as the offer price is raised.

The cash for clunkers measure relies on reductions in the stock of older vehicles, and this can only be accomplished relatively slowly. Cost levels per tonne of reduction are generally higher at earlier dates of assessment than in 2015 (figure 5.1). Assessed to the year 2015, after two decades of policy implementation, the lowest marginal cost per tonne of cumulative CO_2 equivalent emissions is of the order of $28 per tonne, rising to about $72 per tonne (table 5.3).

FIGURE 5.3 EFFECTS OF CAR SCRAPPING SCHEME ON EMISSIONS



Note See table 5.1 for the assumed levels of acceptance associated with the various offer prices.
Source BTCE estimates.

TABLE 5.3 CAR SCRAPPING: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1) Offer price	(2) Cumulative reduction: CO_2 equivalent	(3) Change in cumulative reduction: CO_2 equivalent	(4) Social cost of cumulative reduction	(5) Change in social cost	(6) Average social cost[b]	(7) Marginal social cost[c]
(1995–96 $)	(million tonnes)	(thousand tonnes)	($ million)	($ million)	($ per tonne)	($ per tonne)
1996 to 2000						
$893	0.381	0.381	167.2	167.2	439	439
$1082	0.688	0.307	189.7	22.5	276	73
$1223	0.930	0.242	214.3	24.6	230	102
$1338	1.136	0.206	239.7	25.4	211	123
$1447	1.330	0.194	265.6	25.9	200	134
$1545	1.490	0.160	291.5	25.9	196	162
1996 to 2005						
$893	2.342	2.342	315.7	315.7	135	135
$1082	3.860	1.518	406.9	91.2	105	60
$1223	5.049	1.189	505.6	98.7	100	83
$1338	6.092	1.043	606.7	101.1	100	97
$1447	7.000	0.908	707.4	100.7	101	111
$1545	7.727	0.727	806.3	98.9	104	136
1996 to 2010						
$893	5.478	5.478	396.7	396.7	72	72
$1082	8.367	2.889	510.0	113.3	61	39
$1223	10.502	2.135	628.4	118.4	60	55
$1338	12.235	1.733	746.3	117.9	61	68
$1447	13.510	1.275	860.0	113.7	64	89
$1545	14.452	0.942	969.3	109.3	67	116
1996 to 2015						
$893	8.834	8.834	451.2	451.2	51	51
$1082	13.446	4.612	581.6	130.4	43	28
$1223	16.857	3.411	716.8	135.2	43	40
$1338	19.671	2.814	850.4	133.6	43	47
$1447	21.845	2.174	979.0	128.6	45	59
$1545	23.583	1.738	1 103.0	124.0	47	71

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

c. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates.

Sensitivity testing

Results were tested for sensitivity to changes in the discount rate, but no disproportionate changes to present values were apparent.

A second sensitivity test was carried out by varying the offer price assumed to correspond to the acceptance level. In one scenario, the offer price was halved (that is, $446 rather than $893 was assumed to result in an acceptance level of 2.5 per cent). Also tested was an assumption that offer prices would need to be 50 per cent higher than in table 5.2: an acceptance level of 2.5 per cent would require offers of $1340. Table 5.4

TABLE 5.4 SENSITIVITY TESTING: MARGINAL SOCIAL COSTS TO 2015 AND VARIATIONS IN CAR SCRAPPING ACCEPTANCE RATES

(1995–96 $ per tonne of cumulative CO_2 equivalent emissions)

	Offer price		
Acceptance rate (per cent)	*50% lower than table 5.2*	*As in table 5.2*	*50% higher than table 5.2*
2.5	49	55	62
5.0	21	37	54
7.5	33	57	82
10.0	43	74	105
12.5	60	100	141
15.0	77	128	178

Source BTCE estimates.

TABLE 5.5 COMPOSITION OF TOTAL SOCIAL COSTS OF CAR SCRAPPING IN 2015

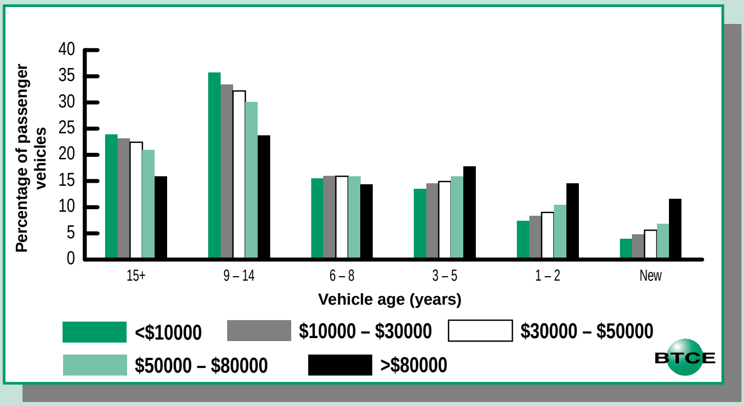
(1995–96 $ million)

	Offer price					
Sector	*$893*	*$1082*	*$1223*	*$1338*	*$1447*	*$1545*
Consumer	–68.6	–156.2	–271.2	–407.3	–568.5	–742.8
Producer	0.7	1.6	2.8	4.3	6.1	8.0
Government	519.3	736.4	985.4	1 253.8	1 541.7	1 838.1
Externalities	–0.1	–0.2	–0.2	–0.3	–0.3	–0.3
Total	451.2	581.6	716.8	850.4	979.0	1 103.0

Note Costs are in present values (1995–96 $) using a 10 per cent discount rate.

Source BTCE estimates.

FIGURE 5.4 DISTRIBUTION OF VEHICLE OWNERSHIP BY VEHICLE AGE AND HOUSEHOLD INCOME



Note The distribution of vehicles relates to 1993.

Source Based on a survey conducted by the Institute of Transport Studies, Graduate School of Business, The University of Sydney, under contract to the BTCE.

shows marginal costs with different assumptions about offer prices. Marginal costs decrease with lower offer prices and increase with higher ones. However, changes in marginal costs are not exactly proportional to changes in offer prices due to the influence of other costs.

EQUITY ISSUES

Table 5.5 presents a breakdown of the distribution of total costs between motorists (consumers), fuel producers, government and externalities for 2015.

Government revenue would fall so that taxpayers generally would be worse off, and oil companies would experience lower profits because of reduced sales of fuel. The health and environmental benefits of a car scrapping measure would be minor.

Motorists selling old cars generally benefit, in that they obtain a surplus over their valuations of them (Alberini, Edelstein et al. 1994, p. 31). However people who accept offers for their vehicles (as well as other consumers) would be likely to face somewhat higher prices in the market for older replacement cars, due to a reduced supply of cheaper older vehicles. As a group, motorists also save on fuel costs as the number of fuel-inefficient vehicles in the car fleet is reduced.

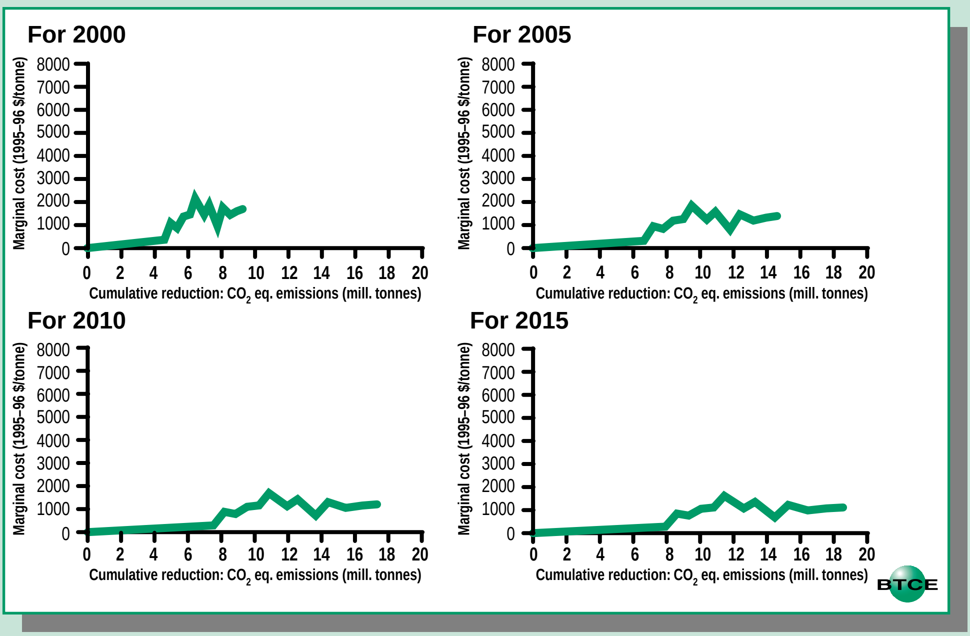
The effect on households of different incomes is difficult to gauge accurately. People accepting an offer for scrapping their vehicle generally receive more than their valuation of the car (or they wouldn't sell it). So households owning older cars stand to benefit from the policy. Figure 5.4 indicates clear differences between the ages of cars owned by households with different incomes, except for 6–8 year old vehicles which are evenly distributed among households of all income groups. However, ignoring those households with incomes of $80 000 and over, there is not a very marked difference in the age of vehicles owned by households of different incomes. Quite often, higher income households may possess 'older' cars as 'second' vehicles. Thus the car scrapping measure may be only mildly slanted toward providing benefits to lower income households.

...AT A GLANCE

Regular engine tuning can reduce both CO_2 and noxious non-CO_2 greenhouse gas emissions. Tuning all pre-1980 vintage cars biannually would result in a cumulative reduction of 8 million tonnes of CO_2 equivalent emissions by 2015, at a marginal social cost of $282 per tonne. Extending the tuning to all vintages up to 1991 would result in a maximum reduction of 18.6 million tonnes of CO_2 equivalent emissions by 2015, at a relatively high marginal cost for the 1991 vintage of about $1100 per tonne.

- Biannual tuning would generate fuel saving benefits to motorists of about $1.33 billion over the period 1996 to 2015. The Commonwealth Government would lose $612 million in fuel excise, while state and territory governments would lose $126 million in business franchise fees.
- Starting with a group of the oldest cars in the fleet (all vintages up to 1979), this chapter estimates the costs and greenhouse gas reduction potential of tuning the engines of cars manufactured in each additional year up to 1991.
- Tuning has limited potential for reducing greenhouse gas emissions from well maintained late model cars.

FIGURE 6.1 CAR ENGINE TUNING: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 6 COMPULSORY TUNING OF CAR ENGINES

Random or compulsory tests of vehicle exhaust emissions provide a means of controlling excessive emissions. Testing of vehicle emissions requires the setting of standards against which the tests can be performed. Such standards can be set for noxious emissions on the basis of health effects and dose–response relationships.

Carbon dioxide is the main greenhouse gas emitted by cars. A standard based on CO_2 would be tantamount to setting fuel efficiency standards for cars, because the amount of CO_2 produced is closely related to fuel used. (Fuel saving technology in new cars is explored in chapter 3.)

An alternative to accelerated fuel saving technology is to minimise the fuel used by all vehicles, so that they more closely conform to the fuel consumption specifications to which they were designed. A plausible method of doing so is to ensure that vehicle engines are tuned regularly. The measure assessed in this chapter is the compulsory tuning of engines in all designated vehicles, irrespective of emission levels.

Motor industry sources recommend that most engines be tuned at least twice a year (W. Johnston, NRMA, pers. comm. 13 October 1995; C. Mullins, Toyota Australia, pers. comm. 25 October 1995). The 'compulsory tuning' instrument analysed here involves two tunings per year.

McConnell (1990, p. 2) points to the fact that the results of her study on the costs and benefits of the vehicle inspection and maintenance program in the Maryland region corroborate the claim made by Reitze (1979) that the benefits of such programs would decline over time. Compulsory tuning of vehicles can be expected to be more suitable as a short-term policy for reducing greenhouse gas emissions. Advances in vehicle technology such as emission control equipment and on-board diagnostic devices, coupled with more stringent emission standards, mean that recent model vehicles have different tuning requirements, and their potential for emission reductions from biannual tuning is limited. As older vehicles are progressively scrapped from the Australian car fleet, it could be expected that the benefits of a compulsory tuning program would decline.

Compulsory tuning, like inspection and maintenance programs, is a fairly blunt instrument in that it imposes costs on all vehicles, irrespective of whether they are performing optimally in regard to fuel consumption. However, the cost effectiveness of compulsory tuning could be enhanced by some form of targeting.

There is considerable evidence that emissions generally increase with age. Grant (1995, p. 35), who assessed the 'gross emitter' problem in California, concludes that a high proportion of total emissions from cars and trucks comes from old and/or poorly maintained vehicles. He cites evidence that older cars tend to pollute from five to twenty times more than newer vehicles that are functioning properly.

EPA (1994, p. 6) cites US studies by Anderson (1990) and by the USEPA (cited in Anderson & Lareau 1992) which indicate that average emissions from older vehicles can be three to ten times higher than well maintained late model vehicles. Anilovich and Hakkert (1995, p. 11) and Bruno and Improta (1995, p. 192) found a definite correlation between CO and HC emission levels and vehicle age, higher emissions being associated with older vehicles. In assessing the cost effectiveness of a vehicle inspection and maintenance program, McConnell (1990, p. 13) found that inspecting older model cars appeared to yield additional benefits at a relatively low marginal cost relative to the average cost for the program as a whole. FORS (1996, p. iv), in a study of car vehicle emissions in Australia, concluded that there is clear evidence that exhaust pollution levels increase with age and kilometres travelled, although this deterioration varies widely among individual vehicles.

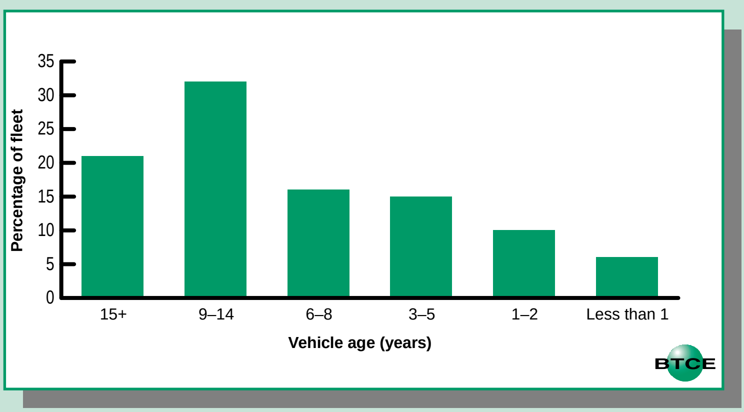
But the common perception that old, poorly maintained 'clunkers' are responsible for a large proportion of emissions is only partially correct, according to Duleep, Meszler and Schroeer (1995, p. 2). They observe that malfunctioning cars do emit most vehicle pollution, but that these malfunctions are spread evenly through the fleet regardless of age. Duleep et al. cite studies by Stephens and Cadle (1991) and Ashbaugh and Lawson (1991) which found that roughly half of CO emissions come from between 10 and 20 per cent of the fleet and that between 50 and 80 per cent of HC come from about 20 per cent of the fleet (not necessarily the same 20 per cent). These studies found that the high emitters tended to be distributed throughout the fleet and that approximately 20 per cent of 1 to 2-year-old cars were high emitters.

The foregoing findings are consistent with those of FORS (1996, p. 90) which observes that no group of Australian vehicles of a particular age can be totally ignored in terms of their emission producing potential. FORS (1996, pp. 48–49) found that HC and CO emissions from 'old' cars (manufactured between 1970 and 1979) were higher than from 1980–1985 cars, but not to an extent that makes the older cars appear to be significantly different. FORS found that NO_x emissions from older cars were lower than from 1980–1985 cars and were not significantly higher than the overall fleet average.

In the sample of cars it tested, FORS (1996, p. vii) identified vehicles in all age groups that emitted extremely high levels of pollution (up to 100 times typical new car levels). However, FORS (1996, pp. vi–vii) also found that cars in the Australian fleet that were 10 to 16 years old had the highest levels of HC and CO tailpipe emissions per annum for three reasons: they have fairly high average emissions, they are driven fairly long distances each year, and they are still quite numerous because of Australia's low fleet turnover rate.

The mean age of the Australian fleet in 1991 was 9.4 years, while the median age was eight years. Figure 6.2 shows the age distribution of the Australian fleet as at 1993: over 50 per cent of the fleet was over nine years old. Although older vehicles generally have higher levels of

FIGURE 6.2 PERCENTAGE OF AUSTRALIAN FLEET BY AGE OF VEHICLES IN 1993



Source Based on information provided by the Institute of Transport Studies, Graduate School of Business, The University of Sydney, under contract to the BTCE.

emissions, this is to some extent offset by the relatively lower average kilometres travelled annually by these vehicles. The age distribution of the Australian fleet and the findings of FORS (1996) suggest that engine tuning has the potential to produce reasonable reductions in emissions of the Australian car fleet in the short term.

FORS National In-Service Emissions (NISE) study

The major data source used in this analysis was the NISE study conducted by FORS. The FORS study had several objectives, which included estimation of the total exhaust emissions of the current passenger vehicle fleet before and after tuning, and gathering information to assess the need for inspection programs (FORS 1995). On the basis of a random selection of households in Sydney and Melbourne by AGB McNair Pty Ltd, FORS tested over 600 privately owned passenger cars, comprising five major makes (Ford, Holden, Toyota, Nissan and Mitsubishi). These five makes represent over 70 per cent of the total passenger vehicle fleet. AGB McNair also collected information on the types of vehicles used, the degree of use, frequency of maintenance, and respondent's income. About 70 per cent of the vehicles tested were manufactured in and after 1986 (catalyst equipped). The rest were manufactured mainly between 1980 and 1985 (non-catalyst) but included several vehicles manufactured between 1970 and 1979.

Vehicles were tested when they were received at the testing station and again after they had been tuned as far as possible to manufacturer's specifications. The difference in emissions before and after tuning provides an indication of the maximum achievable reduction in emissions from vehicles of a particular type and vintage. Several tests were carried out by FORS, including steady state idle tests and ADR 37/00 exhaust and evaporative emissions tests. The analysis in this chapter is based on FORS results for the ADR 37/00 tests (the current Australian standard).

METHODOLOGY

Estimation of emission changes due to tuning

The database of the FORS NISE study was used to estimate changes in emissions and fuel consumption after tuning. The analysis is based on the main sample of about 600 vehicles in the FORS (1996) database and excludes some supplementary vehicles (including 50 1992–93 vehicles) tested by FORS. The FORS emissions data are the most comprehensive and up-to-date available for Australia. A report on the NISE study has been published (FORS 1996).

For the purposes of the BTCE analysis, vehicles in the Australian passenger fleet were assigned to the following seven classes:

Micro	≤4 cylinders, < 1400 cc
Small	4 cylinders, 1400–1900 cc
Medium	4 cylinders, >1900 cc
Upper Medium 1	6 cylinders, < 3000 cc
Upper Medium 2	6 cylinders, ≥3000 cc
Large	≥8 cylinders
Luxury	Specific makes and engine capacities (such as Ford LTD, Ford Fairlane, Holden Statesman and Holden Calais)

As part of contracted work for the BTCE, the Institute of Transport Studies at The University of Sydney's Graduate School of Business used ABS data to provide estimates of the number of vehicles in each class and vintage (and average kilometres travelled) for urban vehicles only. These data were used to allocate the entire Australian fleet to the seven classes, and the vehicles in each class were disaggregated by year of manufacture (vintage).

Scrapping rates of vehicles were calculated using the CARMOD model developed by the BTCE **(appendix VII)**. The model generates the expected distribution of the numbers of vehicles of each vintage in the fleet over time. The distributions generated by the model were used to estimate overall costs and benefits of tuning in different years.

The difference in emissions following tuning was calculated using FORS data for CO, HC and NO_x. The value representing the change in emissions for each vintage and class used was the average of the total number of values relating to that vintage and class from the FORS database. For example, if two micro class vehicles of 1980 vintage had been tested, the value for the change in emissions used in the analysis was the average of the two values. Likewise, differences in fuel consumption (in litres per 100 kilometres) before and after tuning were calculated and converted to the equivalent amount of CO_2 in grams per kilometre.

Because the FORS data related to a sample of vehicles in the fleet, it did not include vehicles of all vintages in each class. Consequently, there were several gaps or unknown values in the database developed for the BTCE study. These unknown values (the change in emissions of a vehicle of a particular class and vintage due to tuning) were estimated using known values. The value in a class adjacent to the class with the missing value (and corresponding to the same vintage as the missing value) was used as a proxy for the missing value. This method of estimating missing values assumes that, because of the prevailing level of technology, vehicles of the same vintage as that of the vehicle with the missing value but belonging to an adjacent class would have similar emissions.

The process described above generated a database with values representing the average changes in emissions due to tuning all passenger vehicles by vintage and class. The total change in emissions (in grams per kilometre) due to tuning for all vehicles of each vintage in each class was obtained by multiplying the average change in emissions for that vintage and class by the corresponding number of vehicles and the average kilometres travelled. The total change in emissions (grams) was calculated in this manner for each gas (HC, CO, NO_x and CO_2) and then converted to CO_2 equivalents.

HC emissions from vehicles arise from exhaust output as well as from running, evaporative and refuelling losses, whereas NO_x and CO are emitted only with exhaust gases. The compulsory tuning instrument assessed in this chapter targets the HC exhaust emissions only (and NO_X, CO and CO_2 exhaust emissions). According to estimates by the EPA (1994, p. 6) of New South Wales, only 40 per cent of HC emissions come from the exhaust. The EPA estimates that running, evaporative and refuelling HC emissions account for 25, 25 and 10 per cent respectively.

Estimation of costs and benefits

The procedure described above to estimate changes in emissions was also carried out to estimate changes in fuel consumption for each vintage by class. The procedure provides estimates of the average change (improvement) in fuel consumption in terms of litres per 100 kilometres. These values, multiplied by the estimated average price of petrol in 1995–96 of 74.2 cents per litre (BTCE 1996b) and average kilometres travelled by class, yields estimates of the monetary value of fuel savings to motorists.

Reduced fuel consumption due to engine tuning will effectively reduce driving costs, which could tend to increase distance travelled (the so-called 'rebound effect') and thereby also increase emissions. No allowance has been made for such a possibility because the estimated average fuel saving per vehicle was considered small enough to have a negligible effect on driving behaviour.

Environmental effects of emissions include health losses (morbidity and mortality), soiling, corrosion, vegetation damage and impaired visibility. The estimates used in this analysis are based on values extracted from the general literature **(appendix X)**. These estimates relate mainly to health effects and should be regarded as likely order of magnitude values because uncertainties in estimation produce a range of unit costs which vary by more than a factor of 100 across the different studies. The (urban) value used for HC and NO_x was $0.07 per kg and for CO $0.002 per kg.

Transport emissions in major urban areas and in other areas were assumed to account for 57 and 43 per cent of total emissions, respectively, based on estimates of annual kilometres travelled by cars in these areas (ABS 1993a, p. 13). On the basis of this assumed distribution of emissions, the weighted average health cost for HC and NO_x was estimated at $0.05 per kg. The weighted average cost for CO was negligible.

The value of travel time was taken as $15.19 per person-hour, an estimate based on an average of values of time for each capital city in Australia weighted by the expected population of each city in 1996 **(appendix XIII)**.

Assuming that vehicle owners are required to travel to an accredited garage or tuning facility, leave their vehicles for tuning, and pick up their vehicles later the same day, the total amount of time required for travel per year has been assumed to be 1 hour 20 minutes (for two tunings). The total amount of fuel consumed for travel and in the tuning process was assumed to be 2 litres per tuning. The average cost of two tunings and parts per year carried out by an accredited tuning facility has been assumed to be $357, based on data from the NRMA.[1]

1. Average cost estimates are: 3-hour major tune $189; 1.5-hour minor tune $94; for each tuning, cost of parts $71 (N. Finnigen, NRMA, pers. comm. 19 June 1995). It is assumed that if tuning is carried out twice each year, the overall cost of tuning over time will be less than if tuning is carried out infrequently. It has therefore been assumed that the total cost of tuning comprises a major and minor tune, plus parts associated with a single tuning (that is, the sum of $189, $94 and $71).

Administrative costs were estimated as the incremental costs of administering a compulsory tuning scheme, given that all states and territories already have administrative facilities in place for vehicle registration. It is envisaged that these same administrative and personnel facilities could be used to operate a compulsory tuning scheme. Administration costs and costs of inspecting tuning facilities were estimated from data provided by the ACT Motor Registry.

The cost of inspecting accredited garages and tuning facilities for enforcement and checking purposes was estimated at $65.00 per inspection. Substantial administrative costs would be incurred initially in processing applications from garages and tuning facilities, checking their premises, equipment and technical competence and approving or disapproving applications. Thereafter, annual administrative costs would be incurred mainly for random checking of garages and tuning facilities and investigating complaints. It has been assumed that, on average, 200 premises per state or territory would be inspected each year, generating a cost of $13 000 per year per state or territory. On average, the cost of administration and enforcement was estimated at $3.29 per vehicle per year.

The loss of profits by fuel producers due to reduced fuel sales as a result of tuning was estimated at 2 per cent of the value of the difference in retail fuel revenue (PSA 1995, p. 52 and Australian Institute of Petroleum Ltd pers. comm. 20 February 1996).

The costs and benefits of compulsory tuning are summarised in table 6.1. Net costs of vehicle tuning are obtained by summing all costs and subtracting health and fuel saving benefits (net of Commonwealth fuel tax and state and territory business franchise fees).

The analysis of emissions data suggests that, in general, older vehicles generate more emissions per kilometre driven than late model vehicles. Tuning older vehicles will thus be more cost effective in terms of emission reduction relative to newer, more fuel-efficient vehicles. However, by starting with the older vehicles and progressively targeting newer models, the ‘compulsory tuning’ instrument can be implemented at levels of increasing stringency. In this way, the largest potential reductions in emissions can be achieved first.

TABLE 6.1 CAR ENGINE TUNING: COSTS AND BENEFITS

Description	*Cost or benefit ($)*	*Unit of measurement*	*Data source*
Costs			
Cost of travel time	20.25	Per vehicle per year	BTCE estimate
Cost of fuel (4 litres)	2.97	Per vehicle per year	BTCE estimate
Administration cost (including accreditation and enforcement)	3.29	Per vehicle per year	ACT Motor Registry pers. comm.
Tuning cost	354.00	Per vehicle per year	NRMA pers. comm.
Average loss of producer profit	0.27	Per vehicle per year	BTCE estimate
Benefits			
Health benefits (HC and NO_x)	0.05	Per kg reduced	BTCE estimate (appendix X)
Average fuel saving	26.45	Per vehicle per year	BTCE estimate

Source BTCE estimates based on data from various sources.

RESULTS

For the entire sample of cars tested by FORS average changes in emissions before and after tuning were 16 per cent for HC, 25 per cent for CO and 9 per cent for NO_x (FORS 1996, p. ix).

The BTCE analysis shows that the levels of emissions, and to some extent the average difference in CO_2 equivalent emissions, per vehicle-kilometre travelled, before and after tuning, decrease as newer cars are tuned (figure 6.3). This finding is confirmed by FORS (1996, p. 36), which observes that well maintained cars less than four years old are unlikely to generate significant emission reductions from tuning.

Marginal costs of emission reduction per tonne of CO_2 equivalent have been estimated for each vintage, commencing with the group of pre-1980 vintages and progressively including single additional vintages up to 1991. Costs of reducing emissions in the ‘snapshot’ years 2000, 2005, 2010 and 2015 have been estimated in 1995–96 $ using a 10 per cent discount rate.

The average reduction in fuel consumption due to tuning was estimated at 2 per cent. The average value of the fuel saving per vehicle per year was estimated at $26.45. The aggregate value of fuel savings, if cars manufactured before 1980 and up to 1991 were tuned, would amount to about $232 million per year. Over the period 1996–2015, tuning these

TABLE 6.2 CAR ENGINE TUNING: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1) Vintage range	(2) Cumulative reduction: CO_2 equivalent (million tonnes)	(3) Change in cumulative reduction: CO_2 equivalent (tonnes)	(4) Social cost of cumulative reduction ($ million)	(5) Change in social cost ($ million)	(6) Average social cost[b] ($ per tonne)	(7) Marginal social cost[c] ($ per tonne)
1996 to 2000						
Pre 1980	4.60	4.60	1 653.56	1653.56	359	359
Pre 1980–80[d]	4.95	0.35	2 068.77	415.21	418	1 186
Pre 1980–81	5.33	0.38	2 400.50	331.73	450	873
Pre 1980–82	5.72	0.39	2 931.86	531.36	513	1 362
Pre 1980–83	6.11	0.39	3 495.39	563.53	572	1 445
Pre 1980–84	6.41	0.30	4 161.24	665.85	649	2 220
Pre 1980–85	6.96	0.55	4 947.54	786.30	711	1 430
Pre 1980–86	7.25	0.29	5 500.37	552.83	759	1 906
Pre 1980–87	7.75	0.50	5 975.28	474.91	771	950
Pre 1980–88	8.07	0.44	6 537.62	562.34	810	1 757
Pre 1980–89	8.51	0.44	7 176.33	638.71	843	1 452
Pre 1980–90	8.92	0.41	7 822.16	645.83	877	1 575
Pre 1980–91	9.26	0.34	8 402.74	580.58	907	1 708
1996 to 2005						
Pre 1980	6.63	6.63	2 083.16	2 083.16	314	314
Pre 1980–80[d]	7.20	0.57	2 622.40	539.24	364	946
Pre 1980–81	7.78	0.58	3 105.52	483.12	399	833
Pre 1980–82	8.38	0.60	3 820.72	715.20	456	1 192
Pre 1980–83	8.99	0.61	4 592.00	771.28	511	1 264
Pre 1980–84	9.5	0.51	5 520.53	928.53	581	1 821
Pre 1980–85	10.40	0.90	6 639.09	1 118.56	638	1 243
Pre 1980–86	10.91	0.51	7 442.14	803.05	682	1575
Pre 1980–87	11.79	0.88	8 146.81	704.67	691	801
Pre 1980–88	12.37	0.58	8 996.50	849.69	727	1 465
Pre 1980–89	13.19	0.82	9 976.11	979.61	756	1 195
Pre 1980–90	13.95	0.76	10 978.56	1 002.45	787	1 319
Pre 1980–91	14.61	0.66	11 887.99	909.43	814	1 378
1996 to 2010						
Pre 1980	7.53	7.53	2 199.18	2 199.18	292	292
Pre 1980–80[d]	8.18	0.65	2 772.05	572.87	339	881
Pre 1980–81	8.85	0.67	3 296.57	524.52	372	783
Pre 1980–82	9.55	0.70	4 062.86	766.29	425	1 095

Continued on next page

TABLE 6.2 CAR ENGINE TUNING: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996 (continued)

(1) Vintage range	(2) Cumulative reduction: CO_2 equivalent	(3) Change in cumulative reduction: CO_2 equivalent	(4) Social cost of cumulative reduction	(5) Change in social cost	(6) Average social cost[b]	(7) Marginal social cost[c]
	(million tonnes)	(tonnes)	($ million)	($ million)	($ per tonne)	($ per tonne)
Pre 1980–83	10.26	0.71	4 893.42	830.56	477	1 170
Pre 1980–84	10.86	0.60	5 899.84	1 006.42	543	1 677
Pre 1980–85	11.94	1.08	7 121.54	1 221.70	596	1 131
Pre 1990–86	12.56	0.62	8 006.50	884.96	637	1 427
Pre 1990–87	13.65	1.09	8 790.73	784.23	644	719
Pre 1980–88	14.39	0.74	9 746.45	955.72	677	1 292
Pre 1980–89	15.45	1.06	10 860.63	1 114.18	703	1 051
Pre 1980–90	16.44	0.99	12 013.84	1 153.21	731	1 165
Pre 1980–91	17.32	0.88	13 072.10	1 058.26	755	1 203
1996 to 2015						
Pre 1980	7.92	7.92	2 230.66	2 230.66	282	282
Pre 1980–80[d]	8.61	0.69	2 812.64	581.98	327	843
Pre 1980–81	9.31	0.70	3 348.37	535.73	360	765
Pre 1980–82	10.05	0.74	4 128.49	780.12	411	1 054
Pre 1980–83	10.81	0.76	4 975.11	846.62	460	1 114
Pre 1980–84	11.45	0.64	6 002.62	1 027.51	524	1 605
Pre 1980–85	12.61	1.16	7 252.33	1 249.71	575	1 077
Pre 1980–86	13.28	0.67	8 159.71	907.38	614	1 354
Pre 1980–87	14.47	1.19	8 966.09	806.38	620	678
Pre 1980–88	15.27	0.80	9 952.14	986.05	652	1 233
Pre 1980–89	16.44	1.17	11 106.26	1 154.12	676	986
Pre 1980–90	17.56	1.12	12 306.35	1 200.09	701	1 072
Pre 1980–91	18.56	1.00	13 413.39	1 107.04	723	1 107

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

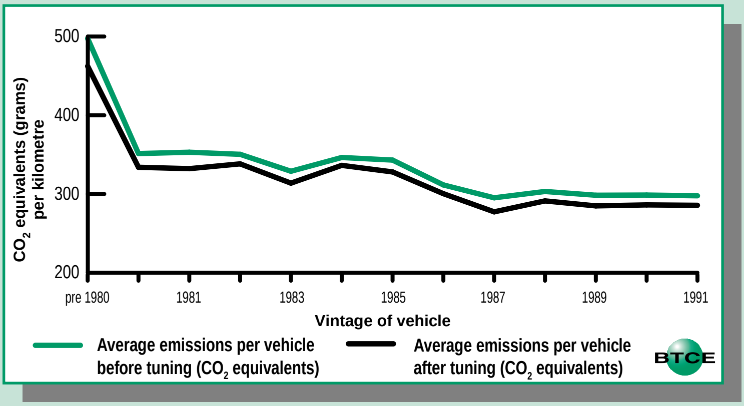
b. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

c. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

d. Pre 1980–80 means 1979 and earlier cars, plus 1980 cars. Pre 1980–81 means the previous category plus 1981 cars.

Source BTCE estimates.

FIGURE 6.3 AVERAGE CO_2 EQUIVALENT EMISSIONS PER VEHICLE-KILOMETRE TRAVELLED BEFORE AND AFTER TUNING, BY VINTAGE



Source BTCE estimates.

cars would generate aggregate fuel savings to motorists of $1.33 billion (1995–96 $).

Table 6.2 shows the cumulative reduction in emissions in terms of CO_2 equivalents and costs for the years 2000, 2005, 2010 and 2015. The maximum cumulative reduction achievable is about 18.5 million tonnes by the year 2015. Figure 6.1 and table 6.2 show that the marginal costs per tonne of CO_2 equivalent emissions reduced range from about $300 to around $2000.

Figure 6.1 and table 6.2 also show that marginal costs tend to rise and fall, but against an overall rising trend as more (and newer) vehicles are tuned. As the potential for reducing emissions from newer vehicles is limited, marginal costs tend to rise as these vehicles are compulsorily tuned.

Table 6.2 also shows that marginal costs decrease over time. This analysis refers only to vehicles manufactured between about 1971 and 1991 and their distribution in the fleet over time. The pattern of marginal costs therefore reflects the numbers of vehicles of each vintage between 1971 and 1991 in the fleet over time (which depends on the number of vehicles entering the fleet and the number scrapped each year). The fall in marginal costs over time is due to the smaller number of these vehicles in the fleet over time and the effect of discounting. Many of the vehicles of early vintage (for example, 1971 to about 1985) would have been scrapped by 2015.

Catalytic converters and unleaded petrol have been required for all new vehicles since 1986. The impact of these changes is reflected in a marked increase in marginal cost for the 1986 vintage as shown in table 6.2, because of the smaller reductions in emissions achieved.

Sensitivity testing

Sensitivity analysis was conducted by varying the costs associated with tuning, travel time, fuel consumed and administration and re-estimating marginal costs at a discount rate of 10 per cent. The high and low values used in the sensitivity analysis are set out in table 6.3, together with the medium (or most likely) values.

Tables 6.4 and 6.5 show results for 2015 for the low and high cost scenarios, respectively. Marginal cost per tonne of CO_2 equivalent reduced ranges from $187 to $1135 for the low cost scenario and from $376 to $2076 for the high cost scenario.

TABLE 6.3 COSTS VARIED IN SENSITIVITY TESTING: CAR ENGINE TUNING

Activity incurring costs	*High cost*	*Medium cost*	*Low cost*
Litres of fuel per vehicle	6	4	2
Costs ($/year)	(4.45)	(2.97)	(1.48)
Travel time (minutes)	120	80	40
Level of tuning	Two major tunes plus one set of parts	One major tune, one minor tune plus one set of parts	Two minor tunes plus one set of parts
Costs ($/year)	(449)	(354)	(259)
Number of tuning facilities inspected	300	200	100
Costs ($/year)	(19 500)	(13 000)	(6 500)

Note The figures in brackets are the annual costs associated with the respective activities (for example, 6 litres of fuel are assumed to cost $4.45).

Source BTCE estimates.

TABLE 6.4 CAR ENGINE TUNING: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS FOR 2015 (LOW COST SCENARIO)

Vintage range	*Cumulative reduction CO_2 equivalent (million tonnes)*	*Social cost of cumulative reduction ($ million)*	*Average social cost ($ per tonne)*	*Marginal social cost ($ per tonne)*
Pre 1980	7.92	1 479.99	187	187
Pre 1980–80[b]	8.61	1 891.59	220	597
Pre 1980–81	9.31	2 269.48	244	540
Pre 1980–82	10.05	2 822.54	281	747
Pre 1980–83	10.81	3 421.09	316	788
Pre 1980–84	11.45	4 147.62	362	1 135
Pre 1980–85	12.61	5 035.48	399	765
Pre 1980–86	13.28	5 682.82	428	966
Pre 1980–87	14.47	6 252.34	432	479
Pre 1980–88	15.27	6 952.80	455	876
Pre 1980–89	16.44	7 770.06	473	699
Pre 1980–90	17.56	8 622.25	491	761
Pre 1980–91	18.56	9 407.70	507	785

a. All costs are cumulated from 1996 to 2015, expressed as net present values (1995–96 $) using a discount rate of 10 per cent. Average and marginal costs have been rounded to the nearest dollar.

b. Pre 1980–80 means 1979 and earlier cars, plus 1980 cars. Pre 1980–81 means the previous category plus 1981 cars.

Source BTCE estimates.

The cost estimates for the three scenarios were tested for sensitivity to the discount rate, with no unexpected results.

EQUITY ISSUES

Compulsory tuning would impose costs on all vehicle owners unless it were targeted at vehicles of particular classes or vintages. The results in this chapter suggest that it would be relatively more cost effective to target older vehicles. Figure 5.4, which shows the proportion of vehicles by age owned by different income groups in Australia, provides an indication of possible welfare effects of compulsory tuning.

TABLE 6.5 CAR ENGINE TUNING: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS FOR 2015 (HIGH COST SCENARIO)

Vintage range	*Cumulative reduction CO_2 equivalent (million tonnes)*	*Social cost of cumulative reduction ($ million)*	*Average social cost ($ per tonne)*	*Marginal social cost ($ per tonne)*
Pre 1980	7.92	2 981.33	376	376
Pre 1980–80[b]	8.61	3 733.68	434	1 090
Pre 1980–81	9.31	4 427.26	476	991
Pre 1980–82	10.05	5 434.45	541	1 361
Pre 1980–83	10.81	6 529.13	604	1 440
Pre 1980–84	11.45	7 857.63	686	2 076
Pre 1980–85	12.61	9 469.19	751	1 389
Pre 1980–86	13.28	10 636.61	801	1 742
Pre 1980–87	14.47	11 679.85	807	877
Pre 1980–88	15.27	12 951.48	848	1 590
Pre 1980–89	16.44	14 442.46	879	1 274
Pre 1980–90	17.56	15 990.45	911	1 382
Pre 1980–91	18.56	17 419.08	939	1 429

a. All costs are cumulated from 1996 to 2015, expressed as net present values (1995–96 $) using a discount rate of 10 per cent. Average and marginal costs have been rounded to the nearest dollar.

b. Pre 1980–80 means 1979 and earlier cars, plus 1980 cars. Pre 1980–81 means the previous category plus 1981 cars.

Source BTCE estimates.

Although there is a fairly marked difference between the proportions of vehicles owned by low and high income households for new vehicles and vehicles aged 1–2 years, the disparity narrows for vehicles 3–8 years old, and widens again for vehicles 9–15 plus years old.

However, if households with annual incomes greater than $80 000 (about 7 per cent of Australian households in 1993) are excluded, then the spread of vehicle ages is roughly similar for all income groups. Compulsory tuning is therefore likely to affect the community in a fairly even manner. It must be noted, however, that the proportions of vehicles in figure 5.4 would include the probably older second (or additional) vehicles of high income households.

Where motorists already tune their vehicles regularly, compulsory tuning would represent a ‘no regrets’ activity. If only older vehicles are targeted for tuning, the higher private cost of maintenance would encourage faster scrapping of vehicles that do not warrant the additional expense.

Compulsory tuning would provide some private benefits to motorists through better vehicle performance and lower fuel consumption. The value in 1996 of aggregate savings in fuel consumption to motorists over the period 1996–2015 would be $1.33 billion. Motorists who are competent in tuning engines themselves and who tune them regularly would incur unnecessary costs for professional tuning. Unless exemptions were provided (such as for owners of vintage cars which contribute little to emissions due to low distances travelled), some minor inequities could arise.

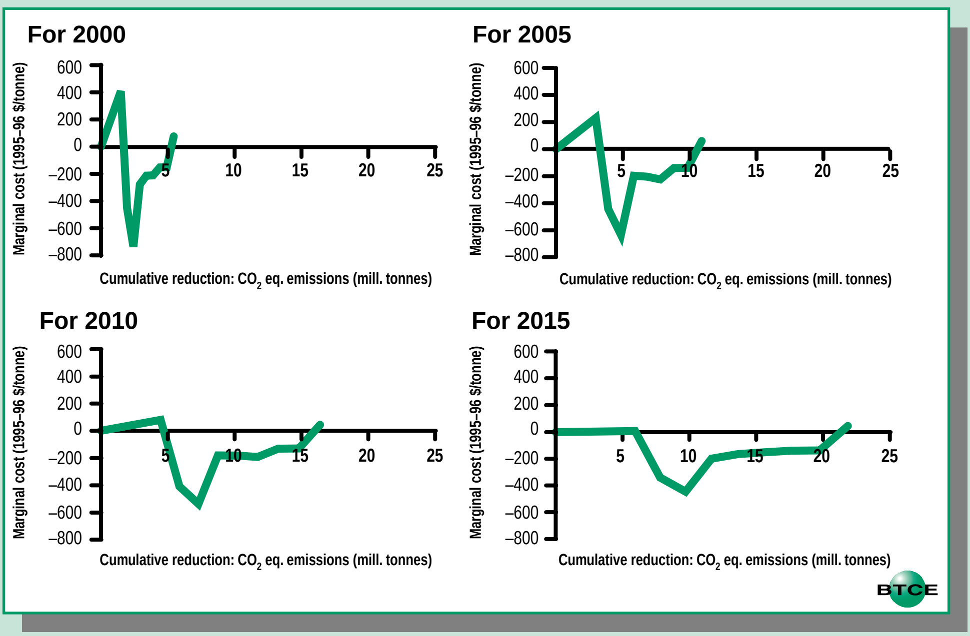
Over the period 1996–2015, compulsory tuning would result in a loss to the Commonwealth Government of $612 million, while losses in business franchise fees to state and territory governments would be $126 million.

...AT A GLANCE

City-wide commuter parking charges would reduce greenhouse emissions by lowering the attractiveness of using private automobiles for travelling to and from work. But even city-wide parking charges of $12 per day would result in a cumulative reduction of only about 4 per cent in emissions of greenhouse gases generated by urban passenger travel in the major capital cities. However, the benefits of reductions in traffic congestion and noise make urban parking charges a 'no regrets' measure.

- Governments were assumed to impose a uniform parking charge on urban commuters who park all day, no matter what part of a city they park in (that is, not just central business districts). Such charges represent a levy on commuters who use cars, but would not affect through travel, or time-limited parking for shopping or other purposes.
- Applied in six Australian capital cities, parking charges would reduce congestion at peak periods, as well as cutting greenhouse emissions.
- Lower-income commuters would be hit harder than higher income groups, and commuters whose jobs are located in areas well serviced by public transport would have an advantage over other commuters.

FIGURE 7.1 URBAN COMMUTER PARKING CHARGES: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 7 URBAN COMMUTER PARKING CHARGES

It is sometimes suggested that increasing the cost of parking in urban areas is an obvious and effective way of reducing car travel. *The Economist* (1996, pp. 14–15) points out that people are already familiar with parking charges, so they would understand and be more likely to accept the adoption of such a measure. While parking charges are a very indirect method of reducing the level of greenhouse emissions, the public currency of the notion made the analysis of its costs desirable.

In a study of household choice between automobile travel and public transit in 1964, Gillen (1977) tested the effect of parking charges imposed on commuters travelling to work within the square mile of the Toronto central business district. Gillen (1977, p. 198) found that 'individuals are relatively more responsive to changes in parking costs than to changes in other money costs' (for example, vehicle operating costs), but that the effect of parking fees on car use had been overestimated in previous studies. Assuming an existing modal split of 75 per cent and 25 per cent respectively, between car use and public transport, Gillen (1977, p. 196) estimated an elasticity of –0.31 of car trips to parking charges. That is, a 10 per cent increase in parking charges was expected to reduce the number of work trips by car into central Toronto by about 3 per cent.

The policy option adopted for analysis in this chapter is that of a charge for all-day parking charge in all areas of six Australian capital cities, not just the central business districts (CBDs). Only commuters (those who drive to work and park all day) would be affected. Through traffic (picking up or dropping off passengers, or driving through residential locations), and shopping (where time-limited parking is available) would not be affected. Effectively what is being analysed is a 'trip charge' on commuters: a charge for bringing a vehicle to work is comparable to a change in fares on public transport.

A choice of travel mode involves consideration of the relative attractiveness of modes in relation to factors such as comfort, privacy, convenience, travel time, financial cost, and safety. It is the 'bundle' of characteristics of each mode that determines a commuter's choice, because each bundle offers a different overall level of satisfaction. Parking charges would alter the balance because they increase the financial cost of using a car compared with using a bus or walking.

Not all drivers would switch from cars to other modes in response to a parking charge. Some will continue to drive despite a parking charge because the generalised costs of travel by car may fall. Others may prefer to pay the higher cost and to continue to drive because of the relatively high degree of residual satisfaction from factors such as convenience, or because public transport is not readily accessible.

In practice, a policy instrument such as the imposition of urban parking charges is potentially fraught with problems of inconsistencies and unintended policy consequences.

In some localities public transport infrastructure may not be adequate for a switch away from cars. While additional buses can usually be provided, expansion of capacity of rail services could pose difficulties given current network congestion in a number of cities, which worsens with population growth. An increase in the conflict between passenger and freight demand for rail networks would further worsen the problem. Shop owners in specific locations might be affected adversely or beneficially. Bacon (1993, p. 277) suggests that shoppers make the largest number of trips after commuters, and that they increase their trips at lower levels of congestion. The effective cost to commuters of parking charges would also depend on how much of the revenue collected is used in ways that benefit them, offsetting any direct financial costs. Business might incur costs if employees sought to circumvent all-day parking charges by regularly leaving their workplace to shift vehicles between timed spaces. And considerable resource costs could potentially be incurred by the community as a result of agitation or legal action by interest groups for the repeal of parking charges, if such a policy were particularly unpopular.

For obvious reasons, it was not possible to explore all the possible complications of the effects of a city-wide parking charge. To the extent that many indirect costs have not been taken into account, the results of the analysis should be regarded as providing a considerable underestimate of costs.

METHODOLOGY

Because the objective was to estimate consequential changes in greenhouse emissions, the analysis focused on the effect of parking charges on total kilometres travelled (and therefore fuel usage), rather than on the number of trips. Responses by commuters to different levels of parking charge (applied uniformly across the whole city) were estimated using the ITS/BTCE model of urban household travel behaviour **(appendix VI)**.

The ITS/BTCE model allows simulation only of per car per day parking charges (commuters are likely to pay per car per day), in each zone in each of the six capital cities. In the basecase, a lump sum parking charge of $4 per car per day is assumed only for cars that park in the central zone of each city. Parking in other zones in the model attracts no charge. Timed and curb-side parking is assumed implicitly but is not included in the model as a choice available to commuters, who presumably would generally not be attracted to short-term parking.

The zones designated CBDs in the ITS/BTCE model represent different employment shares (the number of jobs in the zone relative to the number of jobs across the city) in the six cities. The share of employment in north-east Brisbane, for example, is 9.4 per cent of employment for the city as a whole. Central Canberra, at 52 per cent, has the most centralised employment, while shares in the other capitals range from 26 to 32 per cent. North Sydney, the fourth largest business district in Australia, with 200 000 'parking events' per month (Reinhart 1995, p. 48) is not designated a CBD and attracts no parking charge in the model's basecase.

Uniform daily parking charges were applied simultaneously to all zones in each city in the ITS/BTCE model in $1 increments (from $4 to $12) to test commuter responses. These charges were applied each year from 1996 to 2015. Annual changes in kilometres travelled by car are based on 225 days per year to allow for weekends and public holidays. Results were aggregated for Adelaide, Brisbane, Canberra, Melbourne, Perth, and Sydney, and values of kilometres travelled and social costs incurred were compared with the basecase result. Litres of petrol consumed were converted to CO_2 emissions at the rate of 2.26 kg of CO_2 emissions per litre. Non-CO_2 gas emissions were added according to their CO_2 equivalence (appendix IV) to provide an overall estimate of CO_2 equivalent emissions.

A direct result shown by the ITS/BTCE model when city-wide parking charges are imposed is a switch by commuters away from cars to public transport. However, buses and trains themselves emit greenhouse gases. Allowance was made for increased emissions from public transport by scaling up the basecase emissions for public transport (BTCE 1995c, table V.13) by the increase in its modal share determined from the ITS/BTCE model. No account was taken of any increased use of taxis, walking or bicycles.

There are no obvious, simple schemes for implementing a city-wide commuter parking charge of the sort posited in this chapter. Actual implementation would require a good deal of consideration because of the complexities involved. One possibility would be a legislatively based commuter charge akin to a consumption or services tax, imposed on all commercial off-street parking, manual inspection and collection for on-street parking, and a form of voucher, or pre-payment, scheme for off-street parking that is currently free. It was assumed that people continue to park, under a scheme of city-wide parking charges, in the same places they park in the basecase. No additional land costs, therefore, were factored in. Where on-street and off-street parking charge facilities exist, it was assumed they continue to be used. Where such facilities are not installed, they would have to be installed to facilitate a city-wide scheme of charges. The parking spaces commuters use would need to be marked to designate them as commuter parking spaces to make inspection and discrimination between types of parking more practicable. Various parking meter and parking lot technologies have different advantages in terms of fixed costs, labour costs and user considerations. Luk (1995a, 1995b), Young (1991), and Giummarra and Luk (1995) survey some of the options.

Implementation costs of mechanical parking charge facilities were assumed to be incurred in the year 1996. It was assumed arbitrarily that a quarter of commuter parking would be all-day on-street, and three-quarters off-street. When not parking on residential property, the percentage of motorists choosing on-street rather than off-street parking is higher overall, according to Luk (1996, p. 18), but this includes shoppers and other non-commuting motorists. Few commuters would be expected to park on-street, especially in CBDs, where on-street parking is scarce and usually time-limited, but more could be expected to do so near suburban centres.

The two main capital expenses of implementing parking charges would be installing on-street parking meters where none exist, and marking spaces as commuter parking spaces. Installing meters, and line-marking for the number of non-commercial commuter parking spaces required in 1996, would occur in 1996, and additional marking would be done each year to accommodate the growth in car commuting that occurs with the growth of a city's population.

Approximations of costs were obtained from several council technicians and industry associations. The approximations varied greatly according to factors ranging from the technology used for meters to the width of a painted line and the type of paint used. The estimates used in this chapter for on-street meter installation were provided by Ian Lovett of North Sydney Council (pers. comm. 12 July 1996), while line-marking costs were assumed from a range of cost estimates for different materials supplied by Boral Road Services' Steve Litman (pers. comm. 12 July 1996). Line-marking costs involved the assumptions that the materials used would cost an average of $1.40 per linear metre and that each commuter parking space would require an average of three linear metres of paint or thermoplastics. The costs of installing meters at curbs included four-bay electronic meters ($1835), posts and cabling ($308), underground wiring (averaging $10 per metre, or $30 per on-street space) and a power supply unit supplying 40 meters ($1750). Costs were therefore assumed to be an average of $4.20 to mark off-street commuter parking spaces and an average of $581 to mark an on-street space and install meters.

Commuters trying to evade parking charges could present a costly problem for shops and shoppers, both of whom benefit from the free parking. Because the social costs of any distortions have not been factored into the analysis, the costs presented in table 7.4 are an underestimate.

Parking inspectors and administrators would be required, to limit the extent of any evasion and to correct any local distortions. The number of inspectors would depend on the average daily commuter parking level. More inspectors would probably be needed at higher levels of parking charges, but their number was assumed to be related to the average number of commuters who park, rather than to the incidence of evasion. Table 7.1 shows the average amount of daily commuter parking by city for selected years and parking charges. The estimates are based on the output of the ITS/BTCE model, which projects the number of annual one-way commuter car trips for every year, and parking charge level. The number of commuter trips is divided by two to give the amount of annual commuter 'parking events', then divided by 225 (the number of days in the working year used in the model) to give a daily average.

TABLE 7.1 AVERAGE NUMBER OF PROJECTED DAILY PARKING EVENTS BY CITY, YEAR AND PARKING CHARGE

Parking charge[a]	*Year*	*Adelaide*	*Brisbane*	*Canberra*	*Melbourne*	*Perth*	*Sydney*	*Total*
Basecase[b]	1996	95 951	32 897	54 163	260 054	105 421	213 594	762 081
(CBD commuter	2000	98 599	35 334	57 777	271 132	113 947	220 846	797 634
parking charge only)	2005	101 415	38 356	62 445	283 954	124 513	229 509	840 194
	2010	103 866	41 280	67 062	295 532	134 943	237 530	880 214
	2015	106 044	44 107	71 365	306 242	145 151	244 913	917 823
Basecase[c]	1996	305 454	371 943	105 133	851 097	359 611	857 401	2 850 639
(total commuter	2000	313 724	399 664	112 067	888 428	389 297	888 382	2 991 562
‘parking events’	2005	322 552	434 125	121 111	932 076	426 124	925 256	3 161 244
city-wide)	2010	330 250	467 474	130 133	971 844	462 622	959 463	3 321 786
	2015	337 174	499 767	138 444	1 008 865	498 542	991 356	3 474 148
$4	1996	302 074	364 997	104 139	838 782	354 759	838 946	2 803 697
(all zones)	2000	310 287	392 240	111 051	875 718	384 068	869 861	2 943 225
	2005	318 997	425 997	119 988	918 776	420 388	905 816	3 109 960
	2010	326 574	458 714	128 814	957 964	456 379	939 259	3 267 706
	2015	333 417	490 372	137 043	994 493	491 802	970 289	3 417 417
$6	1996	299 330	360 873	102 948	829 474	350 957	826 437	2 770 019
(all zones)	2000	307 453	387 827	109 788	866 178	379 979	857 030	2 908 256
	2005	316 095	421 219	118 629	908 748	415 903	892 452	3 073 045
	2010	323 595	453 542	127 362	947 526	451 503	925 437	3 228 965
	2015	330 361	484 852	135 506	983 748	486 543	956 244	3 377 254
$8	1996	296 484	356 580	101 673	819 950	346 890	813 617	2 735 193
(all zones)	2000	304 546	383 213	108 436	856 311	375 609	843 844	2 871 959
	2005	313 061	416 248	117 173	898 361	411 114	878 733	3 034 690
	2010	320 475	448 146	125 806	936 717	446 299	911 033	3 188 476
	2015	327 172	479 102	133 859	972 589	480 934	941 617	3 335 272

Continued on next page

TABLE 7.1 AVERAGE NUMBER OF PROJECTED DAILY PARKING EVENTS BY CITY, YEAR AND PARKING CHARGE (continued)

Parking charge[a]	*Year*	*Adelaide*	*Brisbane*	*Canberra*	*Melbourne*	*Perth*	*Sydney*	*Total*
$10	1996	293 473	352 148	100 309	810 009	342 550	800 493	2 698 982
(all zones)	2000	301 440	378 471	106 989	846 120	370 952	830 387	2 834 359
	2005	309 887	411 075	115 616	887 627	406 011	864 804	2 995 020
	2010	317 207	442 568	124 142	925 542	440 756	896 573	3 146 788
	2015	323 821	473 098	132 098	961 018	474 964	926 716	3 291 715
$12	1996	290 324	347 492	98 854	799 911	337 926	787 067	2 661 575
(all zones)	2000	298 245	373 541	105 447	835 567	365 994	816 459	2 795 254
	2005	306 568	405 663	113 957	876 541	400 585	850 500	2 953 813
	2010	313 802	436 678	122 368	913 885	434 863	881 785	3 103 381
	2015	320 340	466 922	130 219	949 041	468 619	911 289	3 246 429

a. Numbers not shown for $5, $7, $9 and $11 parking charges.

b. Basecase parking numbers are for the central business district (CBD) only. The numbers represent the average number of daily ‘parking events’ which attract a commuter parking charge in the basecase.

c. The average number of commuters parking daily in every zone of each city, whether or not they pay a commuter parking charge. Under city-wide commuter parking charges of $4, $6, $8, $10 and $12, car commuters in all zones would pay for parking, so no distinction is made for CBD commuters.

Source BTCE estimates based on the ITS/BTCE model.

Commuters who park in the CBD already pay a daily parking charge (the basecase) either directly or through costs incurred by employers who provide free parking. Imposition of a city-wide parking charge will involve additional inspection and collection costs only for non-CBD commuters. The extra number of non-CBD commuters was calculated by subtracting the number of average daily CBD commuters in the basecase in a given year from the total number in the city (table 7.1).

For example, the ITS/BTCE model projects an average of 878 733 commuter cars parking per day in the whole of Sydney in the year 2005 under an $8 parking charge. Table 7.1 shows that the number of Sydney commuters who would currently (in the basecase) pay for parking on an average day in the year 2005 is 229 509. Costs were therefore estimated for the difference: 649 224 spaces. Empty spaces also would need to be inspected, but the main expense would come from the labour employed to inspect and collect for occupied spaces.

Luk (1995a, p. 21) estimates the cost of inspecting and collecting from 1000 single-space on-street meters to be $23 648 and $59 000 respectively per year. Because it was assumed that no additional land is acquired for the purpose of implementing the scheme, costs were estimated for physical inspection and collection at existing parking facilities and administration by conventional means. Inspection, collection and administration under the parking charge scheme considered here would be for both on- and off-street parking, commercially and government provided. It would require inspectors intruding onto commercial property and a high degree of scrutiny of both commercially and government provided parking. Inspectors would need to check every space and vehicle, to ensure that accurate collection was being made, as well as deterring evasion. The cost per thousand spaces used was $82 648 ($23 648 plus $59 000), but this is necessarily imperfect because it does not take into account existing technology in parking facilities, nor of parking inspectors and collectors already employed in the areas where the charges would be implemented. Under the assumption of $82 648 per thousand spaces, the example of Sydney in the year 2005 with $8 per day parking charges would cost $53 657 065 in total that year to run the scheme.

The same difference between average daily basecase CBD parking and average number of daily 'parking events' in a scenario was used to estimate capital costs. For example, under city-wide commuter parking charges of $8, there is a difference of 1 973 112 'parking events' in the year 1996 (table 7.1) which implies that 1 973 112 commuter parking spaces would have to be delineated, and a quarter of those provided with meters. In each year after, however, line-marking costs are estimated for additional commuter parking spaces only. Under $8 urban commuter parking charges, for example, 101 213 extra commuter parking spaces would need to be marked over 1996 to 2000.

A reduction in car-kilometres travelled in each city would produce benefits in terms of reduced congestion, accidents and emissions of noxious exhaust gases. Congestion, accident and environmental costs were all estimated on the basis of vehicle-kilometres travelled (VKT) and added to the resource costs attributed to reducing greenhouse emissions with parking charges. The benefits of lower congestion were estimated from the reduction in VKT **(appendix XIII)**. The reduction in VKT was also used to estimate, from earlier BTCE research, the benefits of fewer accidents using an average cost of 4 cents per kilometre (appendix X). Urban environmental benefits were estimated for kilograms of CO_2 with a value from a range of estimates of environmental damage from noxious emissions **(appendix X)**.

RESULTS

All results depend critically on the extent to which commuters reduce the amount they travel in response to changes in parking charges. In table 7.2, the elasticity of commuter trips with respect to parking charges increasing from $4 to $5 is given as –0.03. If parking charges were to increase by 10 per cent, from $4 to $4.40, then the number of commuter trips would be reduced by about three tenths of one per cent. Table 7.2 gives some indication that commuters' responses will be relatively slight in the long run, in reduction of number of commuter trips, commuter VKT and total VKT. The elasticities indicate slightly higher responsiveness at higher parking charges, but they are still very low.

Figure 7.2 illustrates the relatively weak effect of parking charges on the total number of kilometres that commuters travel by private automobile (table 7.2). Although a CBD commuter pays $8 (or 200 per cent) more in charges under a $12 commuter parking charge scheme, and the average household pays 948 per cent more in a year (table 7.6), the total number of kilometres travelled by commuters using their cars is only about 6.8 per cent lower. Table 7.3 shows that commuters in cities such as Adelaide and Canberra are generally less responsive in terms of trips to a parking charge, presumably because of less well developed systems of public transport.

TABLE 7.2 IMPLICIT[a] LONG-RUN ARC[b] ELASTICITIES OF MEASURES OF TRAVEL WITH RESPECT TO URBAN COMMUTER PARKING CHARGES

Parking charges[c]	*Commuter trips[d]*	*Commuter VKT[e]*	*Total VKT[f]*
Basecase–$4	–0.02	–0.01	–0.01
$4–$5	–0.03	–0.03	–0.01
$5–$6	–0.03	–0.03	–0.02
$6–$7	–0.04	–0.04	–0.02
$7–$8	–0.05	–0.05	–0.02
$8–$9	–0.05	–0.06	–0.03
$9–$10	–0.06	–0.06	–0.03
$10–$11	–0.07	–0.07	–0.03
$11–$12	–0.08	–0.08	–0.04

VKT Vehicle-kilometres travelled

Note Implicit arc elasticities were estimated by taking the percentage difference in a measure's 1996–2015 total value as given by the ITS/BTCE model and dividing it by the percentage difference in the parking charge. Percentage differences are calculated by dividing the difference in a measure, before and after, by the average between the two values. Elasticity = %ΔTrips/%ΔParking charge. For example, the percentage change in commuter trips from the parking charge increasing from $8 to $9 is given by the difference between the number of trips at $9 and $8 divided by the average of trips at $8 and $9. Similarly, the percentage change in parking charge is given by ($9 – $8)/$8.50. In the example:

$$\text{Elasticity} = \frac{(27\ 225 \text{ million} - 27\ 403 \text{ million})\ /27\ 314 \text{ million}}{(\$9 - \$8)/\ \$8.50} = -0.06$$

a. Results are given on a national basis, aggregating results for Adelaide, Brisbane, Canberra, Melbourne, Perth and Sydney. Because of its structure, the ITS/BTCE model (appendixes V and VI) does not generate demand functions familiar in conventional microeconomics. Elasticities were estimated only by implication from different equilibrium pairs of parking charge levels and VKT (or commuter trips) and are shown to two decimal places.

b. Because parking charges increase by more than infinitesimally small amounts (an increase from $8 to $9 is 11.8 per cent) the elasticities in this table are 'arc elasticities', not 'point elasticities'. They are estimated over an arc of the demand curve, not at a point on the demand curve.

c. Parking charges are applied equally to all zones in a city, not just the central business district.

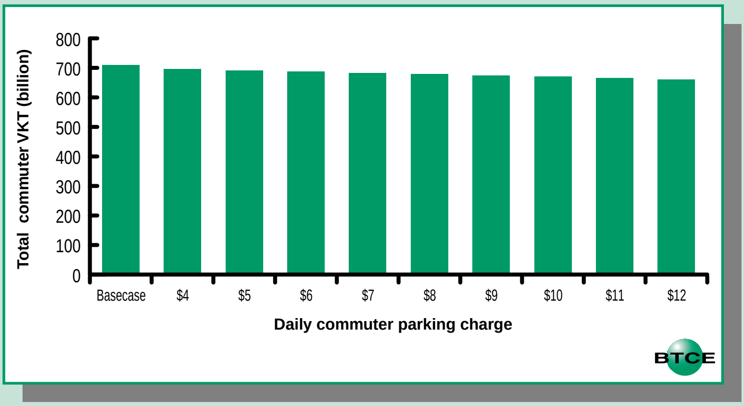
d. Commuter trips are one-way private car journeys made to, from, or at work.

e. Commuter VKT are kilometres travelled during commuter trips.

f. Total VKT includes commuter VKT plus other urban VKT.

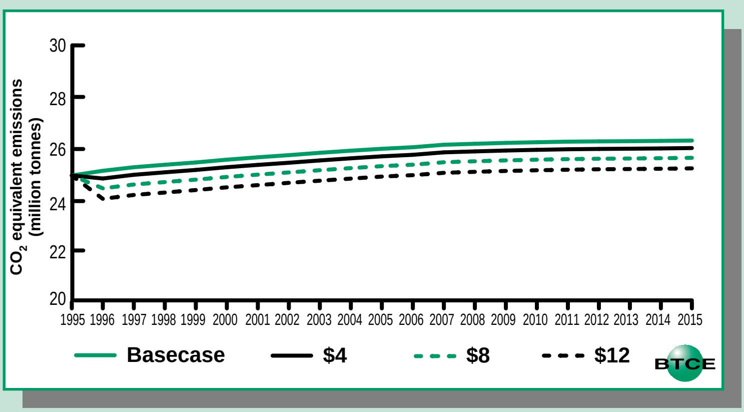
Source BTCE estimates based on the ITS/BTCE model.

FIGURE 7.2 URBAN COMMUTER PARKING CHARGES: TOTAL COMMUTER VEHICLE-KILOMETRES TRAVELLED 1996–2015



Source BTCE estimates based on the ITS/BTCE model of the six major capital cities.

FIGURE 7.3 URBAN COMMUTER PARKING CHARGES: ANNUAL GREENHOUSE GAS EMISSIONS FROM URBAN PASSENGER TRAVEL 1996–2015[a]



a. Parking charges are applied city-wide. Refer to table 7.1 for the number of commuters who pay each charge in the various years.

Source BTCE estimates based on the ITS/BTCE model of the six major capital cities.

TABLE 7.3 PERCENTAGE CHANGE IN THE NUMBER OF COMMUTER TRIPS 1996

Parking charge	*All*	*Adelaide*	*Brisbane*	*Canberra*	*Melbourne*	*Perth*	*Sydney*
$4	–1.64	–1.10	–1.85	–0.92	–1.44	–1.35	–2.15
$8	–4.03	–2.91	–4.10	–3.22	–3.65	–3.54	–5.11
$12	–6.61	–4.91	–6.52	–5.86	–5.99	–6.03	–8.20

Source BTCE estimates based on the ITS/BTCE model.

TABLE 7.4 URBAN COMMUTER PARKING CHARGES: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Description of intensity[b]	*Cumulative reduction: CO_2 equivalent*	*Change in cumulative reduction: CO_2 equivalent*	*Social cost of cumulative reduction*	*Change in social cost*	*Average social cost[c]*	*Marginal social cost[d]*
($ per day)	*(million tonnes)*	*(million tonnes)*	*($ million)*	*($ million)*	*($ per tonne)*	*($ per tonne)*
1996 to 2000						
$4	1.48	1.48	605	605	409	409
$5	1.95	0.47	395	–211	203	–447
$6	2.42	0.47	46	–349	19	–743
$7	2.91	0.49	–88	–134	–30	–273
$8	3.40	0.49	–192	–104	–56	–212
$9	3.89	0.49	–297	–105	–76	–214
$10	4.40	0.51	–376	–79	–85	–155
$11	4.92	0.52	–454	–78	–92	–150
$12	5.44	0.52	–414	40	–76	77
1996 to 2005						
$4	2.97	2.97	684	684	230	230
$5	3.90	0.93	273	–411	70	–442
$6	4.85	0.95	–328	–601	–68	–633
$7	5.82	0.97	–518	–190	–89	–196
$8	6.80	0.98	–717	–199	–105	–203
$9	7.80	1.00	–940	–223	–121	–223
$10	8.81	1.01	–1 082	–142	–123	–141
$11	9.85	1.04	–1 225	–143	–124	–138
$12	10.90	1.06	–1 162	63	–107	59

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TABLE 7.4 URBAN COMMUTER PARKING CHARGES: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996 (continued)

(1) Description of intensity[b] ($ per day)	*(2)* Cumulative reduction: CO_2 equivalent (million tonnes)	*(3)* Change in cumulative reduction: CO_2 equivalent (million tonnes)	*(4)* Social cost of cumulative reduction ($ million)	*(5)* Change in social cost ($ million)	*(6)* Average social cost[c] ($ per tonne)	*(7)* Marginal social cost[d] ($ per tonne)
1996 to 2010						
$4	4.46	4.46	356	356	80	80
$5	5.87	1.41	–217	–573	–37	–406
$6	7.29	1.42	–980	–763	–134	–537
$7	8.75	1.46	–1 243	–263	–142	–180
$8	10.23	1.48	–1 513	–270	–148	–182
$9	11.72	1.49	–1 800	–287	–154	–193
$10	13.26	1.54	–2 001	–201	–151	–131
$11	14.81	1.55	–2 203	–202	–149	–130
$12	16.39	1.58	–2 133	70	–130	44
1996 to 2015						
$4	5.94	5.94	49	49	8	8
$5	7.81	1.87	–589	–638	–75	–341
$6	9.72	1.91	–1 440	–851	–148	–446
$7	11.66	1.94	–1 826	–386	–157	–199
$8	13.63	1.97	–2 151	–325	–158	–165
$9	15.63	2.00	–2 454	–303	–157	–152
$10	17.68	2.05	–2 738	–284	–155	–139
$11	19.75	2.07	–3 023	–285	–153	–138
$12	21.86	2.11	–2 925	98	–134	46

Note Discrepancies were observed in projected government revenue in repeated runs of the ITS/BTCE model with a parking charge of $10. The social costs for $10 parking charges are set at the average of social costs for $9 and $11 charges.

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. Parking charges applied to commuters city-wide.

c. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates based on the ITS/BTCE model for Melbourne, Sydney, Brisbane, Adelaide, Perth and Canberra.

Reductions in greenhouse gas emissions would be modest (figure 7.3). With a $12 parking charge (the maximum), the total amount of greenhouse gases emitted between 1996 and 2015 would be lower by about 21.9 million tonnes. This is a reduction of only 4.23 per cent from cumulated basecase emissions for urban passenger travel in the six major capital cities, of 517 million tonnes. Moreover, as charges increased, taxis might become a real option for commuters. Switching by commuters to taxis (which would not incur parking charges) could vitiate any greenhouse emission reductions otherwise achieved. Table 7.4 indicates how much emissions will decrease in snapshot years, given a range of parking charges, and the associated social costs of imposing city-wide parking charges on commuters. (A negative cost is a social benefit.) Most of the social benefits come from a reduction in congestion.

EQUITY ISSUES

Table 7.5 shows the distribution of welfare changes among the private sector, government and externalities.

Some commuters might need to travel to work by private vehicle because of inadequate public transport near the work location, or physical inability to use public transport. Commuters who find private personal transport essential would be affected more than other commuters.

Among the commuters least affected by parking charges would be those who already use public transport and alternative personal transport to get to work. But the least affected commuters would not be entirely unaffected. Regular bus users, for example, would also benefit from the overall reduced congestion through faster travel.

Imposition of parking charges is regressive in the sense that increases in charges represent a greater proportionate cost to those on lower incomes. Table 7.6 indicates the average amount per annum that a household would pay for parking for three charging schedules, compared with the basecase. In the basecase, low income households pay much less proportionately than higher income households. A possible explanation is that fewer income earners in low income households use cars to go to work in the CBD than the income earners in high income households. When parking charges were applied to the whole city in the ITS/BTCE model, the burden increased relatively more for low income households than it did for high income households. High income earners probably also have more choice of mode of transport, reflecting how well their places of residence and work are served by public transport.

TABLE 7.5 COMPOSITION OF WELFARE CHANGES OVER 1996 TO 2015 BETWEEN THE PRIVATE SECTOR, GOVERNMENT AND EXTERNALITIES

(1995–96 $ million)

Parking charge	*Private sector*[a]	*Government*[b]	*Externalities*[c]
$4	–18 804	15 361	3 319
$5	–24 795	21 338	3 924
$6	–30 926	27 500	4 687
$7	–36 821	33 081	5 355
$8	–42 854	38 841	5 928
$9	–48 894	44 525	6 566
$10	–54 973	50 089	7 340
$11	–61 051	55 653	8 113
$12	–67 140	61 094	8 671

Note Discrepancies were observed in projected government revenue in repeated runs of the ITS/BTCE model with a parking charge of $10. The welfare changes in the private and government sectors in this table were compensated for by setting government revenue from $10 parking charges as the average of governmnet revenue from $9 and $11 parking charges.

a. Welfare changes in the private sector are based mainly on commuters' welfare, but they also include the loss suffered by non-commuting motorists incurred by a reduction in the number of vehicles owned by households (BTCE estimates) and the loss to fuel sellers from reduced petrol consumption from reduced travel (PSA 1995, p. 52). It does not include losses to sellers in the car market that would be incurred from the reduction in the vehicle fleet.

b. Government's gain is mainly from extra revenue (particularly from parking charges and public transport) minus the additional costs assumed for administration and inspection.

c. Welfare benefits of externalities is the reduction in accident, health and congestion costs. The ITS/BTCE model does not take full account of the behavioural responses of shoppers and other non-commuting motorists to less commuter traffic nor of commuters who turn to taxis. It is likely that travel is underestimated while the reduction in congestion is overestimated.

Source BTCE estimates based on the ITS/BTCE model of the six major capital cities.

TABLE 7.6 AMOUNT PAID FOR COMMUTER PARKING PER HOUSEHOLD IN 1996, BY HOUSEHOLD GROSS ANNUAL INCOME

(1995–96 $)

Parking charge	*All income groups*	*Less than $10 000*	*$10–30 000*	*$30–50 000*	*$50–80 000*	*More than $80 000*
Basecase	166	89	134	149	165	205
$4	611	562	586	600	612	636
$8	1192	1088	1140	1168	1194	1244
$12	1740	1576	1656	1702	1742	1826

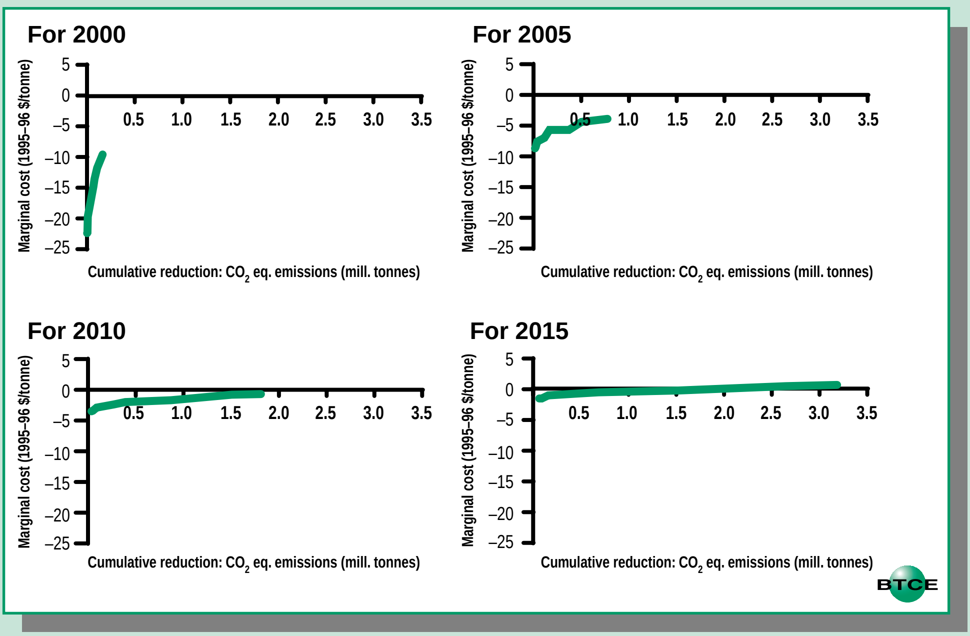
Source BTCE estimates based on the ITS/BTCE model of the six major capital cities.

...AT A GLANCE

Fuel efficiency labelling of new cars using a 'star' rating system similar to that used for domestic electrical appliances can influence buyers to choose more fuel-efficient vehicles. If implemented in 1996, a car labelling scheme would result in a cumulative reduction of about 3 million tonnes of CO_2 equivalent emissions by 2015. Fuel efficiency labelling involves social benefits (negative costs) and is therefore a 'no regrets' measure.

- The aggregate value in 1996 of fuel savings generated up to 2015 would be about $326 million, while the saving to an individual motorist over an average car's lifetime would be about $1000.
- Producers of petrol would lose about $7 million in profits due to reduced fuel sales. The Commonwealth Government would lose about $154 million in petrol excise, while state and territory governments would lose about $32 million in business franchise fees.

FIGURE 8.1 VEHICLE LABELLING: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 8 FUEL EFFICIENCY LABELLING OF CARS

In this chapter, the term 'efficiency' when used in the general context of energy, refers to relative energy consumption. When applied to the fuel consumption of vehicles, *intensity* refers to the number of litres per 100 kilometres travelled, whereas *efficiency* (the inverse of intensity) refers to the number of kilometres travelled per litre.

The energy efficiency of products like electrical appliances and motor vehicles may be known to the seller, but is difficult for buyers to determine. A degree of 'information asymmetry' exists between buyers and sellers. Akerlof (1970) was the first to suggest that markets may not produce socially optimal outcomes in such circumstances.

When an attribute such as energy efficiency varies among competing products, but other attributes are similar, sellers of more energy-efficient products may be unable to obtain a higher price for this superior attribute of their product. In making informed purchasing decisions, buyers generally have to rely on the claims of competing manufacturers. Because of uncertainty on the part of buyers, genuinely more fuel-efficient products may attract prices below their optimal value. A vehicle labelling scheme supervised by the government has the potential to reduce the information asymmetry between buyers and sellers.

A labelling scheme could influence annual fuel consumption in two ways. In the short term, buyers may purchase a more fuel-efficient vehicle within a particular class (engine capacity) or in a class with smaller engine capacities. Average fuel consumption per vehicle would thereby be reduced. In the longer term, the labelling scheme is also likely to spur manufacturers of less efficient models to improve vehicle performance (even the planned implementation of a labelling scheme could have a similar effect). Other things equal, these two effects could contribute to a lower aggregate quantity of fuel consumed by the Australian passenger vehicle fleet.

However, it is also possible that motorists would drive more kilometres each year because of labelling-induced savings on fuel. The greater this 'rebound effect', the smaller would be the overall amount of fuel conserved as a result of the labelling scheme.

Implementation of labelling

Schemes for energy labelling of equipment and appliances exist in several countries including Australia, Canada, the United States, and countries of the European Union (IEA 1995, p. 21). Vehicle labelling programs are mandatory in Japan, Sweden, the United States and United Kingdom, while Canada and New Zealand have voluntary programs (IEA 1987, p. 123; IEA 1984, p. 94).

Refrigerators became the first goods to be energy labelled in Australia in December 1986. The labelling scheme is based on a star rating—the greater the number of stars, the greater the energy efficiency of the appliance. Energy labelling of appliances such as refrigerators, dishwashers and air-conditioners is now mandatory in New South Wales, Victoria, Queensland and South Australia, and other states and territories recognise the labelling (B. Tubb, DPIE, pers. comm. 6 May 1996).

The National Greenhouse Response Strategy (Commonwealth of Australia 1992, p. 26) states that Australian governments will support the provision of vehicle fuel consumption information in labelling and advertising. Government support was to be provided with due regard to Trade Practices Commission (TPC) guidelines on fuel consumption claims by manufacturers and the results of a 1993 Commonwealth study (Wallis 1993) on alternative ways of providing fuel consumption information in dealers' showrooms.

Greenhouse 21C, a document issued by DEST (1995, p. 11), indicates that the Commonwealth Government will work with industry to implement a voluntary mechanism to provide fuel efficiency labelling on all new motor vehicles by the end of 1995. It further states that the Commonwealth Government is committed to introducing mandatory measures if voluntary arrangements cannot be concluded. *Greenhouse 21C* estimates that car fuel efficiency labelling and advertising would result in emission savings of 0.45 million tonnes of CO_2 equivalent by the year 2000 (DEST 1995 p. 19). However, it is not clear whether these policy statements reflect current or future policy directions.

A *Fuel Consumption Guide* (FCG) has been published in Australia by the Commonwealth Department of Primary Industries and Energy (DPIE) since 1980. The FCG is compiled by DPIE from fuel consumption data, based on Australian Standard AS 2877, provided by manufacturers of different models of new cars. The fuel consumption data are based on a standard test cycle rather than on-road testing. DPIE sometimes conducts random tests of vehicles to ensure that the information provided by manufacturers is correct.

Energy labelling can take a variety of forms, ranging from a generic label advising buyers to refer to the FCG, to labels with star ratings incorporating various levels of information on fuel consumption (for example, city cycle and highway cycle estimates).

For the purpose of this analysis it was assumed that labelling of new passenger vehicles would be implemented in 1996 and would be based on a star classification system similar to that used for domestic appliances. The label would indicate the city cycle fuel consumption of the vehicle in litres per 100 kilometres or kilometres per litre. It was also assumed that there would be no constraints on the supply of domestic or imported vehicles, in order to accommodate any substantial shifts, induced by labelling, that might occur in buyers' preferences towards particular makes and models.

Fuel efficiency labelling may be considered an extension of the FCG and could be administered along the same lines. The FCG contains information on fuel intensity (consumption in litres per 100 kilometres), whereas a labelling scheme would involve fuel efficiency ratings, which are considerably more effective in influencing buyer choice (Wilkenfeld, George & Assoc. et al. 1993b p. K1). The greater effectiveness of star ratings is mainly because of their comprehensibility and ease of comparison. Labels would be affixed prominently to the windscreens of all new vehicles displayed for sale. A star rating scheme is also likely to promote greater use of the FCG by buyers comparing cars, if star ratings are included in the FCG.

Effectiveness and implications of labelling

Among Australian fleet buyers, sensitivity to fuel prices and fuel efficiency is typically low (Wilkenfeld, George & Assoc. et al. 1993a, p. 15). Fleet buyers are more concerned with the suitability of vehicles for tasks to be performed, 'whole of life' costs (purchase or lease costs, running costs and reliability) and resale value. Such buyers generally sell their vehicles after about two years of use and savings in fuel costs are likely to be very small relative to differences in whole of life costs between competing makes and models.

Although individuals are more likely to use the labelling scheme, there are some factors that could reduce its effectiveness. One possibility is lack of credibility of information on labels, even in a government administered scheme. For example, the fuel consumption information on labels is unlikely to match values obtained in actual driving modes. Conditions of the AS 2877 test would differ from actual driving conditions due to factors such as speed, wind resistance, congestion, the use of air-conditioners, and seasonal differences in engine warm-up times. Wilkenfeld, George & Assoc. et al. (1993b, p. L4) cite a 1984–85 study by the Society of Automotive Engineers which found that on-road fuel consumption was on average higher than the city cycle and highway cycle values based on the AS 2877 test, by 16 per cent and 35 per cent, respectively.

However, this and other issues could be addressed through information programs and by providing adequate information on the label. In addition to the estimate of fuel consumption, a range could be provided on the label that covers fuel consumption under varied driving conditions.

In cities such as Sydney, retail petrol prices can vary by as much as 10 cents per litre. The saving of between 0.5 and 1.5 litres of petrol per 100 kilometres (the likely range of reduction in fuel consumption achievable by choosing a more fuel-efficient car) would be small compared with the saving per tank of petrol that may be achieved by choosing to purchase petrol from a low priced outlet. Similarly, a substantial discount on the purchase price of a car could reduce the relative attractiveness of a more fuel-efficient model.

Wilkenfeld, George & Assoc. et al. (1993b, p. K3) observe that people need to be given a reason why reducing overall fuel consumption is important and how the consideration of fuel consumption in their decision making can contribute. They recommend the launching of a broad campaign aimed at motorists, to communicate the importance of reducing fuel consumption. Likewise, Nelson English, Loxton & Andrews Pty Ltd (1991b, pp. 33–34) consider it necessary to implement a public education campaign which includes government announcements, testing programs, the FCG, brochures and advertising, together with other market based policies, to augment the impact of a vehicle labelling scheme.

It is also likely that some manufacturers would emphasise the comparative fuel efficiency of their products as represented in labels to differentiate them in the market. Toyota has recently launched an advertising campaign focused solely on the fuel efficiency of its Camry on the basis of information published in the FCG (*Time Australia*, 20 May 1996, p. 16).

A survey by Wilkenfeld, George & Assoc. et al. (1993b, p. K1) shows that there is considerable interest by car buyers in fuel consumption as a purchase factor: 26 per cent of respondents mentioned it unaided. When prompted, 83 per cent said that it was an important factor in choosing a vehicle. The OECD (1991a, p. 26) noted that if opinion polls are any indication, many consumers are willing to pay a premium for environmentally friendlier goods. Also, the concept of star-rated labelling is familiar to Australian consumers.

Like appliance labelling, vehicle labelling has both direct and indirect benefits to consumers. Direct benefits are mainly fuel savings, while indirect benefits (which also accrue to society) are improved environmental conditions. Direct benefits of labelling are readily demonstrable to consumers: the benefit of lower fuel costs accrues over the whole period the vehicle is used. Indirect or social benefits comprise the mitigation of global warming and the reduction of local air pollution.

Perversely, labelling can potentially limit technological improvement. When most or all vehicles of a particular class achieve the maximum star classification, the incentive for further technological improvement may diminish.

Empirical estimates of effectiveness of energy information

Evidence of the effects of energy labelling in the consumer market is not clear-cut. In regard to home appliances, the IEA (1989, p. 100) observes that energy efficiency labels are used by many buyers, but there has been no thorough evaluation of their effectiveness in actually *changing* consumer purchasing decisions. The IEA further states (p. 100) that 'Some consumer studies, however, have indicated that probably most buyers, for a variety of reasons, do not make use of the information provided.'

The OECD (1991a, p. 25), in a study of environmental labelling of a range of products in member countries, observes that the effectiveness of a labelling program can be measured in at least three dimensions: the extent of change brought about in consumer behaviour and in manufacturer behaviour and the benefit to the environment. The OECD concludes that labelling programs appear partially successful by all three measures, but it is difficult to separate the relative contribution of environmental labelling from other factors such as a rise in environmental awareness.

A study by Wilkenfeld, George & Assoc. (1992) estimated the energy impacts and costs of the appliance energy labelling program in Victoria and the rest of Australia up to June 1992. The study found that the labelling scheme had influenced consumer choice and improved the efficiency of manufactured products. Total residential electricity consumption dropped 2.3 per cent below what it would have been, and new appliances were on average about 8.7 per cent more efficient (Wilkenfeld, George & Assoc. 1992, p. 9).

Artcraft Research (1988, p. 14) estimated proportions of private and fleet new car buyers who were aware of, obtained, and used, the FCG, which is currently the closest substitute for energy labels in the vehicle market. Six per cent of the 26 per cent of private buyers (1.5 per cent of all private buyers) who were aware of the guide, were found to have used it to make a purchase decision. About 51 per cent of fleet buyers were aware of the guide, of which 19 per cent (9.7 per cent of all fleet buyers) had used it to make a purchase decision. A survey conducted in 1993 by Artcraft Research (Wilkenfeld, George & Assoc. et al. 1993b, p. K1) showed that awareness of the FCG among a sample of new car buyers was about 22 per cent, but only 2 per cent of the sample had used it to compare vehicles prior to purchase.

A survey by Wallis (1993) examined how consumers intending to buy a new car behaved when confronted with energy labelled vehicles in car dealers' showrooms. The labels were similar to those used on electrical appliances like refrigerators, and were based on a rating of six stars. The surveys were conducted in two showrooms, each displaying a particular make of car. Salespersons were not present, and information on prices of vehicles was not provided.

There was evidence of a change in attitude or preference among 44 per cent of respondents. Fifteen per cent of respondents switched their most preferred vehicle on the basis of fuel consumption. As a result of this switching, average fuel consumption fell from 10.8 to 9.2 litres per 100 kilometres. On the basis of fuel consumption, 20 per cent of respondents strengthened their commitment to their most preferred vehicle, and 9 per cent became less positive about their most preferred vehicle.

According to the IEA (1987, p. 129), only the United States has conducted a comprehensive review of energy information programs. IEA (1984, pp. 99–102) provides a summary of a review, conducted in 1979 and 1980, by the United States Department of Energy (USDOE). The review found that about 70 per cent of new car and light truck buyers were aware of the fuel economy label, and that about half of this proportion (about 35 per cent) used the information for comparison shopping.

A further study was commissioned by the USDOE and the US Environmental Protection Agency in 1981–1982 to review the findings of the 1979–1980 study and to incorporate more recent data. One of the objectives was to determine the influence of manufacturer advertising and government fuel economy information on the purchasing decision. The study found that the fuel label was recognised by 89 per cent of new car buyers in 1981. Of that group, 63 per cent (or 56 per cent of new car buyers) actually used the label in their purchase decision (IEA 1984, p. 102). However, it is not clear from the US studies whether the entire proportion of buyers who used the label changed preferences because of it, or whether they merely used the information in the label as part of their overall decision making process.

METHODOLOGY

The BTCE constructed a model (ENERGYMOD) which incorporated the BTCE model CARMOD **(appendix VII)** to estimate changes in fuel consumed and emissions produced as a result of the assumed implementation of a labelling scheme from 1996. CARMOD takes account of annual average fuel intensity and vehicle-kilometres travelled using historical data from the ABS *Survey of Motor Vehicle Use* (SMVU) and *Motor Vehicle Census* (MVC). The prevailing situation (without labelling) can be regarded as a 'basecase'. To analyse the impact of labelling, ENERGYMOD incorporates assumptions about proportions of new car buyers who switch to more fuel-efficient cars over time and the costs involved in a labelling scheme.

It is not clear whether a labelling scheme, if it were to be implemented, would replace the existing FCG. If the FCG is not discontinued, some proportion of the costs that would be incurred due to the labelling scheme (such as costs of administration and check testing of vehicles) would already be incurred for the FCG. As the overall analysis of the benefits of a labelling scheme is intended to be conservative, estimates of administrative, enforcement and check testing costs that would be incurred by DPIE (the government agency that would be responsible for administering such a scheme) have been included.

The number of new car buyers whose choices over time would be influenced by a labelling scheme, and the consequences of their switching behaviour in terms of reduced fuel consumption of the fleet, is not known.

The introduction of a vehicle labelling scheme may be conceptually likened to the launching of a new product. Information on the scheme is likely to be disseminated both by mass media (advertising, publicity and point of sale material such as posters, placards and leaflets) and interpersonal communication (word of mouth activity). The impact of the labelling scheme over time may be viewed as a 'diffusion' process.

There are several mathematical models in the literature that attempt to describe the diffusion process for different products. Kotler and Roberto (1989, pp. 120, 377) present a rapid penetration model suitable for modelling the diffusion of 'social' products (such as campaigns aimed at influencing community attitudes and behaviour). The model is suitable for products that are expected to have a penetration level of a fraction of the target adopter population, to penetrate the target adopter population rapidly, and at a constant rate. The rapid penetration model (illustrated in figure 8.2) was considered suitable for representing the diffusion of vehicle labelling because of the readily perceived consumer benefits of labelling and its association in the minds of consumers with the existing appliance labelling scheme.

The rapid penetration model, applied to the diffusion of vehicle labelling, may be expressed as:

$$Q_t = r\overline{Q}(1 - r)^{t-1}$$

where:

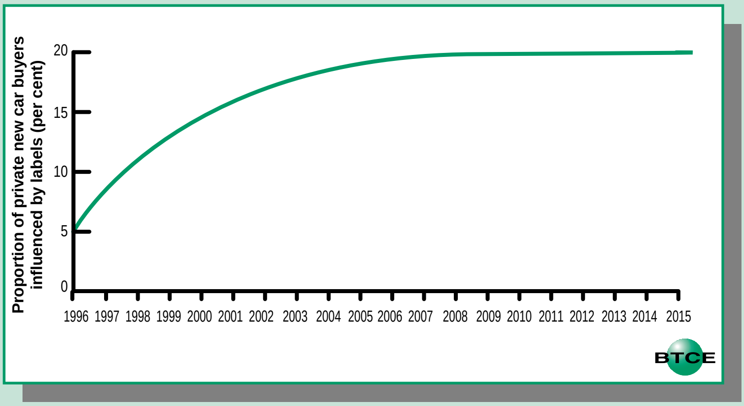
Q_t = increment in cumulative target adopters of labelling (the number of adopters at time t) as a fraction of the potential volume of target adopters;

r = penetration rate (the constant rate at which the remaining potential users of labels would be influenced to choose a more fuel-efficient model);

$\overline{Q}$ = Maximum proportion of adopters of labelling relative to total number of new car buyers (usually determined by carrying out a survey); and

t = time period.

FIGURE 8.2 RAPID PENETRATION MODEL OF DIFFUSION



Source BTCE.

Having recourse to available literature and conservative judgement, the proportion of private new car buyers who switch their preferences as a result of labelling (Q_t) was assumed to increase from 5 per cent in 1996 to 15 per cent in the year 2000, and to reach a maximum of 20 per cent ($\overline{Q}$) by 2010 (the Wallis survey found that 15 per cent of their sample of buyers switched preferences under controlled showroom conditions). These assumptions implied a penetration rate (r) of 23 per cent.

As there was no evidence that fleet buyers would significantly change their purchase preferences on account of labelling, the proportion of buyers who switch was applied only to private buyers (assumed to comprise 48 per cent of new car buyers). On average, the change in the fuel efficiency of a new car purchased each year due to the impact of labelling was assumed to be 1 litre per 100 kilometres (the Wallis study found that the average change was 1.6 litres per 100 kilometres).

The influence of labels on purchase decisions is likely to depend, to some extent, on the amount of expenditure on mass communication such as media advertising and poster campaigns. In general, increasing the amount spent on advertising would result in a greater proportion of a target market purchasing or using a product. However, there are generally decreasing returns to increasing advertising expenditure (Batra et al. 1995, p. 19): as expenditure is increased, the number of additional users will decline, and a point will eventually be reached when additional advertising will not attract additional users.

The influence over time of advertising on the number of buyers who would use labelling in their vehicle purchase decisions is not known. Wilkenfeld, George & Assoc. et al. (1993b, pp. N1, N31) note that major public campaigns should be funded to the extent of at least $3 million to $5 million per year on a sustained basis or not be funded at all, as available evidence suggests that one-off campaigns have not produced significant lasting changes in consumer attitudes or behaviour.

However, government and industry sources have indicated that if a labelling scheme is implemented, it is unlikely that substantial resources would be expended on advertising. The extent of switching behaviour of car buyers assumed in this analysis is expected to occur without substantial expenditure on advertising. Labelling is visually evident and its impact will be enhanced by association with the already familiar appliance labelling scheme and word of mouth activity. A nominal amount of $100 000 per year over the period 1996 to 2015 is assumed to be incurred for producing point-of-sale material such as pamphlets.

Implementation of a labelling scheme would require a technical study to determine the fuel intensity bandwidth to be represented by each star on the label. The cost of this work was estimated generously at $200 000 because previous studies have generated a good deal of information.

It was also assumed that the prevailing system for the compilation of the FCG would apply to the labelling scheme. This means that manufacturers would provide fuel consumption information based on tests of their models to DPIE and produce labels on the basis of this information. DPIE already incurs administrative and enforcement costs (including costs of random testing of vehicles) in compiling the FCG. Nevertheless, an additional amount of $300 000 per year was assumed to be incurred for the administration and enforcement of the labelling scheme.

Manufacturers test their models each year to the AS 2877 standard to provide fuel consumption information to DPIE for the FCG. This test is a part of the broader ADR 37 test that manufacturers have to carry out for all new models released, and would be incurred irrespective of whether the FCG is published. There would therefore be no additional testing cost incurred by manufacturers on account of a vehicle labelling scheme. However, if the FCG is discontinued, a check testing cost may be incurred by DPIE. The estimated annual total cost of testing ($17 000) incorporated in the analysis is based on the assumption that a random sample of 20 vehicles would be tested for city cycle fuel consumption at a cost of $850 per vehicle (S. McDonald, EPA, pers. comm. 24 April 1996).

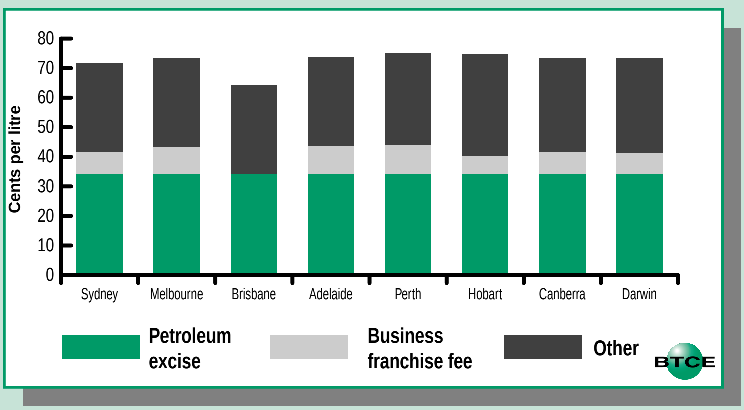
The motor vehicle industry would incur costs in producing and affixing labels to vehicles. The cost of affixing labels would depend mainly on assembly-line procedures. The cost incurred by manufacturers (printing and label affixing costs) was assumed to be $5.00 per label. The total direct cost of labelling incurred by manufacturers and importers would be around $2.5 million per year. The label costs incurred by manufacturers were apportioned according to the proportions (averaged over a period of six years) of vehicles registered in each state and territory (ABS 1993b, p. 7).

The loss of profits by petroleum producers due to reduced fuel sales as a result of labelling was estimated at 2 per cent of the value of the difference in retail fuel revenue (PSA 1995, p. 52 and the Australian Institute of Petroleum Ltd pers. comm. 20 February 1996).

Environmental benefits of reduced fuel consumption were incorporated in the analysis using values for HC, CO and NO_x in **appendix X**.

The retail prices of fuel in each state and territory used in the analysis, are shown in figure 8.3. The figure also shows the petrol tax components of the retail price. The real prices of petrol were assumed to remain unchanged over the period 1996 to 2015. As buyers switch to more fuel-efficient vehicles, the increase in their real income due to reduced cost of travel may generate a tendency to increase the amount of travel they undertake (the 'rebound effect'). The elasticity of vehicle travel (VKT)

FIGURE 8.3 PETROL RETAIL PRICES AND TAXES, 1996



Note Queensland does not levy a business franchise fee on petroleum products.

Source Australian Institute of Petroleum.

with respect to per kilometre fuel cost was assumed to be –0.1. This elasticity was used to estimate the increase in travel and the additional quantity of fuel attributable to the rebound effect. It was also used to estimate congestion costs for Sydney, Melbourne, Brisbane, Adelaide, Perth and Canberra using the methodology in **appendix XIII**. Congestion costs for Darwin, Hobart and regional centres were assessed to be negligible.

Net costs of vehicle labelling over the period 1996 to 2015 were discounted to present values (1995–96 $) using a discount rate of 10 per cent.

Marginal cost curves were constructed by assuming that labelling is introduced successively in all states and territories in ascending order of estimated marginal costs.

RESULTS

Table 8.1 sets out the cumulative reduction in CO_2 equivalent emissions and social costs due to vehicle labelling for the 'snapshot' years 2000, 2005, 2010 and 2015. Figure 8.1 shows marginal costs for these years.

Vehicle labelling would generate a cumulative reduction in CO_2 equivalent emissions of about 3 million tonnes by 2015. Net social costs are negative across almost the full implementation scenario, making vehicle labelling a 'no regrets' measure. Marginal social cost per tonne of CO_2 equivalent emissions reduced varies from $0.70 to minus $22.40 (a benefit).

Table 8.1 shows that net social benefits of vehicle labelling initially increase (up to 2005) and then decrease up to 2015. This pattern of variation is mainly due to the increase over time of the rebound effect and associated congestion. As the stock of more fuel-efficient cars grows, the amount of extra travel by these cars increases. Because of basecase growth in congestion, this extra travel takes place in increasingly congested conditions. The combination of the two effects produces sharply rising congestion costs, which have been incorporated in the analysis.

The aggregate present value of fuel savings to Australian motorists who switch to more fuel-efficient cars on account of labelling over the period 1996 to 2015 was estimated at about $326 million (1995–96 $).

Sensitivity testing

Sensitivity analysis was carried out by varying critical parameters in the analysis to determine upper and lower bound values of marginal costs (low and high benefit scenarios respectively) in the year 2015. The parameters that were varied are shown in table 8.2.

Tables 8.3 and 8.4 show cumulative reductions in CO_2 equivalent emissions and costs for the low benefit and high benefit scenarios respectively.

Marginal costs for all three scenarios were tested for sensitivity to discount rates of 5 and 15 per cent, with no unexpected results.

The results of the sensitivity analysis indicate that, depending on the extent of switching behaviour of private new car buyers, the cumulative amount of CO_2 equivalent emissions reduced between 1996 and 2015 would lie between 1.2 million and 7.3 million tonnes.

EQUITY ISSUES

The direct incremental cost to manufacturers of the labelling scheme per new car sold would be between $2 and $15, representing a negligible fraction of the price of a car. This cost is likely to be borne largely by new car buyers. However, in terms of fuel saved, the present value of the benefit to a buyer of a new car (in 1995–96 dollars) over a 20-year period would be about $1000.

Over time, the benefits of greater fuel efficiency of certain models made apparent by labelling are likely to be transferred to the used car market. Some segments of the used car market (such as low income buyers) would be quite sensitive to the benefits of fuel savings, and cars with high star ratings are likely to command a premium. This effect may influence fleet buyers of new cars to take more serious note of labelling because they typically sell their vehicles after about two years of use.

As car buyers increasingly use labelling in their purchase decisions, manufacturers of less fuel-efficient cars are likely to lose sales and profits to manufacturers of more fuel-efficient models. An overall increase in the market share of smaller vehicles at the expense of larger vehicles is also possible. Such a shift could increase the incidence of fatalities and injuries because occupants of smaller cars are generally more vulnerable to the effects of crashes. If imported cars are more fuel efficient, domestic manufacturers as a whole may lose market share to imports. The loss of sales could result in reduced employment and adverse financial performance by some companies. To the extent possible, affected

TABLE 8.1 VEHICLE LABELLING: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1) Intensity[b]	(2) Cumulative reduction: CO_2 equivalent (tonnes)	(3) Change in cumulative reduction: CO_2 equivalent (tonnes)	(4) Social cost of cumulative reduction ($ million)	(5) Change in social cost ($ million)	(6) Average social cost[c] ($ per tonne)	(7) Marginal social cost[d] ($ per tonne)
1996 to 2000						
NT	1 386	1 386	–0.031	–0.031	–22.40	–22.40
+Tas	4 712	3 326	–0.105	–0.074	–22.30	–22.30
+ACT	8 169	3 457	–0.173	–0.068	–21.20	–19.70
+WA	24 004	15 835	–0.464	–0.291	–19.30	–18.40
+Vic	67 131	43 127	–1.100	–0.636	–16.40	–14.80
+SA	78 468	11 337	–1.254	–0.154	–16.00	–13.60
+Qld	106 127	27 659	–1.581	–0.327	–14.90	–11.80
+NSW	163 722	57 595	–2.133	–0.522	–13.00	–9.60
1996 to 2005						
+Tas	15 597	15597	–0.135	–0.135	–8.70	–8.70
+NT	22 197	6 600	–0.191	–0.056	–8.60	–8.50
+ACT	38 569	16 372	–0.316	–0.125	–8.20	–7.60
+WA	113 751	75 182	–0.839	–0.523	–7.40	–7.00
+SA	166 922	53 171	–1.144	–0.305	–6.90	–5.70
+Vic	371 673	204 751	–2.320	–1.176	–6.20	–5.70
+Qld	502 492	130 819	–2.898	–0.578	–5.80	–4.40
+NSW	774 902	272 410	–3.965	–1.067	–5.10	–3.90
1996 to 2010						
Tas	36 336	36 336	–0.128	–0.128	–3.50	–3.50
+NT	51 198	15 461	–0.181	–0.053	–3.50	–3.40
+ACT	90 075	38 277	–0.292	–0.111	–3.20	–2.90
+WA	266 003	175 928	–0.716	–0.424	–2.70	–2.40
+SA	389 877	123 874	–0.963	–0.247	–2.50	–2.00
+Vic	869 002	479 125	–1.789	–0.826	–2.10	–1.70
+NSW	1 505 590	636 588	–2.270	–0.481	–1.50	–0.80
+Qld	1 811 297	305 706	–2.490	–0.220	–1.40	–0.70

Continued next page

TABLE 8.1 VEHICLE LABELLING: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996 (continued)

(1) Intensity[b]	(2) Cumulative reduction: CO_2 equivalent (tonnes)	(3) Change in cumulative reduction: CO_2 equivalent (tonnes)	(4) Social cost of cumulative reduction ($ million)	(5) Change in social cost ($ million)	(6) Average social cost[c] ($ per tonne)	(7) Marginal social cost[d] ($ per tonne)
1996 to 2015						
Tas	63 776	63 776	–0.094	–0.094	–1.50	–1.50
+NT	90 978	27 202	–0.134	–0.040	–1.50	–1.50
+ACT	158 264	67 286	–0.204	–0.070	–1.30	–1.00
+WA	467 648	309 384	–0.405	–0.201	–0.90	–0.60
+SA	685 065	217 417	–0.514	–0.109	–0.80	–0.50
+Vic	1 527 642	842 577	–0.648	–0.134	–0.40	–0.20
+NSW	2 646 462	1 118 820	–0.123	0.525	–0.10	0.50
+Qld	3 183 748	537 286	0.250	0.373	0.10	0.70

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. The ‘intensity’ of the labelling scheme is varied by introducing it progressively across jurisdictions. For example, in the case of 1996–2000, the figures in the row corresponding to +WA relate to the effects of labelling in Northern Territory, Tasmania, ACT and Western Australia. The varying order of implementation of labelling for different years is due to differences in congestion costs in the different states over time.

c. Average costs (rounded to the nearest ten cents) are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs (rounded to the nearest ten cents) are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates.

TABLE 8.2 PARAMETERS VARIED FOR VEHICLE LABELLING SENSITIVITY ANALYSIS

Variable	*High benefit*	*Medium benefit*	*Low benefit*
Saving in fuel due to switching (litres per 100 km per vehicle)	1.5	1.0	0.5
Label cost ($)	2	5	15
Saturation level of switching (per cent)	30	20	15

Source BTCE.

companies could invest resources in improving the fuel efficiency of their vehicles, thereby enabling them to compete more effectively.

Labelling would bring about a reduction in the aggregate amount of fuel consumed by the Australian fleet. Benefits to motorists from reduced fuel consumption over the period 1996 to 2015 amount to about $326 million. The purchase of reduced amounts of fuel would affect the revenues of fuel producers, wholesalers and retailers. The loss of producer profit was estimated at about $7 million over the period 1996 to 2015. Over the period 1996 to 2015 the Commonwealth Government would lose petroleum excise amounting to about $154 million, while business franchise fees on fuel collected by state and territory governments would fall by about $32 million. As labelling may result in a proportion of new car buyers switching to smaller, less expensive cars, the Commonwealth Government could also lose some sales tax revenue.

TABLE 8.3 VEHICLE LABELLING: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS 1996 TO 2015: LOW BENEFIT SCENARIO

(1) Intensity[b]	*(2)* Cumulative reduction: CO_2 equivalent (tonnes)	*(3)* Change in cumulative reduction: CO_2 equivalent (tonnes)	*(4)* Social cost of cumulative reduction ($ million)	*(5)* Change in social cost ($ million)	*(6)* Average social cost[c] ($ per tonne)	*(7)* Marginal social cost[d] ($ per tonne)
NT	10 110	10 110	0.025	0.025	2.50	2.50
+Tas	33 813	23 703	0.098	0.073	2.90	3.10
+ACT	58 820	25 007	0.175	0.077	3.00	3.10
+WA	173 806	114 986	0.564	0.389	3.20	3.40
+Vic	486 958	313 152	1.777	1.213	3.60	3.90
+SA	567 763	80 805	2.106	0.329	3.70	4.10
+NSW	983 582	415 819	4.051	1.945	4.10	4.70
+Qld	1 183 270	199 688	5.030	0.979	4.30	4.90

a. All costs are net present values (1995–96 $) for costs up to and including the year 2015, using a discount rate of 10 per cent.

b. The ‘intensity’ of the labelling scheme is varied by introducing it progressively across jurisdictions. For example, the figures in the row corresponding to +WA relate to the effects of labelling in Tasmania, Northern Territory, ACT and Western Australia.

c. Average costs (rounded to the nearest ten cents) are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs (rounded to the nearest ten cents) are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates.

TABLE 8.4 VEHICLE LABELLING: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS 1996 TO 2015: HIGH BENEFIT SCENARIO

(1) Intensity[b]	*(2)* Cumulative reduction: CO_2 equivalent *(tonnes)*	*(3)* Change in cumulative reduction: CO_2 equivalent *(tonnes)*	*(4)* Social cost of cumulative reduction *($ million)*	*(5)* Change in social cost *($ million)*	*(6)* Average social cost[c] *($ per tonne)*	*(7)* Marginal social cost[d] *($ per tonne)*
Tas	145 344	145 344	–0.298	–0.298	–2.10	–2.10
+NT	207 339	61 995	–0.418	–0.120	–2.00	–1.90
+ACT	360 684	153 345	–0.657	–0.239	–1.80	–1.60
+WA	1 065 770	705 086	–1.474	–0.817	–1.40	–1.20
+SA	1 561 260	495 490	–2.011	–0.537	–1.30	–1.10
+Vic	3 481 493	1 920 233	–3.307	–1.296	–0.90	–0.70
+NSW	6 031 279	2 549 786	–3.499	–0.192	–0.60	–0.10
+Qld	7 255 753	1 224 474	–3.318	0.181	–0.50	0.10

a. All costs are net present values (1995–96 $) for costs up to and including the year 2015, using a discount rate of 10 per cent.

b. The ‘intensity’ of the labelling scheme is varied by introducing it progressively across jurisdictions. For example, the figures in the row corresponding to +WA relate to the effects of labelling in Tasmania, Northern Territory, ACT and Western Australia.

c. Average costs (rounded to the nearest ten cents) are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs (rounded to the nearest ten cents) are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

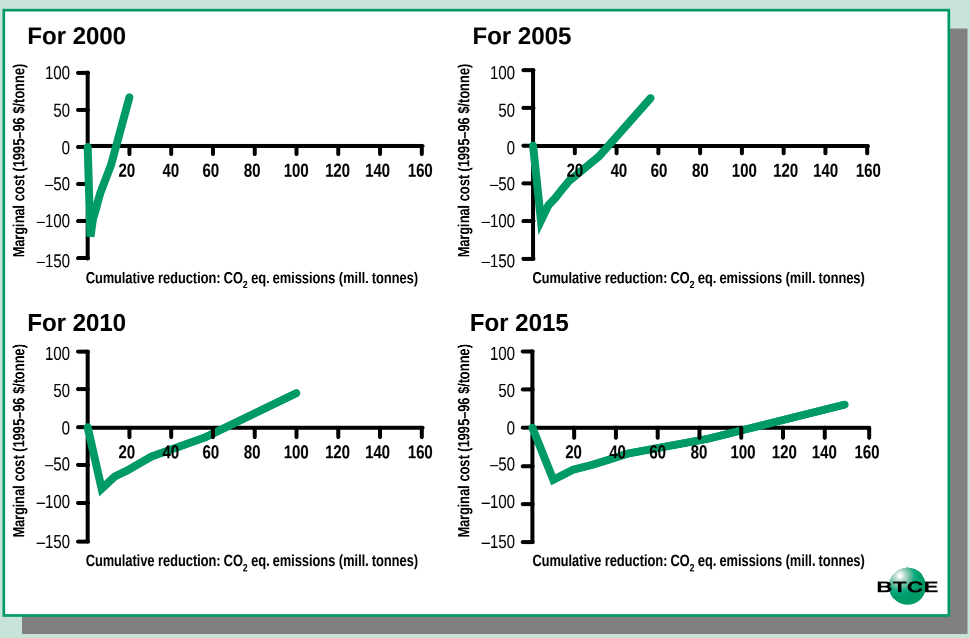
Source BTCE estimates.

...AT A GLANCE

A carbon tax on petrol would reduce greenhouse gas emissions as drivers reacted to higher petrol prices by reducing travel, and by buying more fuel-efficient cars. Annual greenhouse gas emissions would fall by about 20 per cent over basecase emission levels by the year 2015. By the year 2015, there would have been sufficient time for more fuel-efficient vehicles to enter the fleet, and marginal costs are likely to be about $30 per tonne of cumulative CO_2 equivalent reduced at the maximum tax level of $2000 per tonne of carbon.

- It was assumed that a carbon tax would be levied on all fuel used in the economy. Only the effect of the tax on car emissions (taking into account any increase in urban public transport emissions) is assessed in this chapter.
- Various carbon tax levels were investigated. Their effect was to increase the real price of petrol from the 1995–96 average of 74.2 cents per litre to a maximum of $1.97 per litre. Implementation of the tax was assumed to occur in annual steps from 1996 to 2000, with the level remaining constant thereafter to 2015.
- A petrol price of $1.97 per litre would decrease vehicle-kilometres travelled by about 10 per cent each year, generating similar levels of fuel saving each year after 2000. As motorists begin to purchase more fuel-efficient new vehicles, the car fleet gradually becomes more fuel efficient. This improvement in fleet fuel efficiency adds another 10 per cent saving in fuel by 2015, if petrol prices are raised to $1.97 per litre.
- Government revenues would remain almost constant from the year 2000 onwards. At a level of $2000 per tonne of carbon (petrol at $1.97 per litre), the tax would raise about $20 billion a year from passenger vehicles alone.

FIGURE 9.1 CARBON TAX ON PETROL: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 9 A CARBON TAX AND CAR EMISSIONS

Of all the proposed instruments for reducing greenhouse gas emissions, carbon taxes have attracted the most public and international attention.

Carbon taxes are government levies on the carbon content of fossil fuels. They are a good proxy for taxes on emissions because carbon dioxide emissions are closely related to fuel used, and they can be applied in an economically efficient way to the use of fossil fuels in all sectors and in all countries. Because they apply only to carbon, however, they are distortive in terms of more potent greenhouse gases such as chlorofluorocarbons and nitrous oxide.

A carbon tax provides a clear signal to encourage emission reductions through less use of fuel, both from short-term changes in behaviour and through long-run changes in carbon saving transport technologies. Schipper (1995, p. 305) observes that:

> in our exhaustive survey of worldwide changes in energy use over the past twenty years, we found no significant changes in fuel choices or energy efficiency that were not somehow underscored by energy prices favouring the change.

Short-run changes in behaviour can include switching to fuels with lower carbon content, travelling less often or for shorter distances, increased trip linking, changing modes, car pooling, and regular engine tuning. Longer-run responses encompass the development and increased penetration of the vehicle fleet by more fuel-efficient cars or alternatively fuelled vehicles, changes in work or home location, working and shopping from home, and developing less transport-intensive residential areas.

A carbon tax could be applied simultaneously in all countries on all uses of primary energy. It could also be applied in one country alone on all primary energy used, or selectively in specific sectors such as transport.

Because relative prices will be affected differently, the effect of a carbon tax measure will obviously differ according to its coverage. The extent and redistribution of any revenues collected (chapter 2 discusses revenue recycling) will also be crucial to any estimate of costs.

The case analysed in this chapter is that of a carbon tax applied to the whole Australian economy. In analysing the effect on road passenger vehicles (essentially petrol only) it was assumed that prices of other fossil fuels such as diesel or LPG would also increase in proportion to their carbon content, so that relative prices of transport fuels would not change significantly.

In order to simplify the analysis, the effects of a carbon tax were estimated only for cars in Australia, and the effects of revenue recycling were ignored. Tax rates were chosen arbitrarily, and do not represent the damage caused by greenhouse emissions. Taxes were assumed to be applied in addition to existing levels of excise.

METHODOLOGY

A tax on the carbon content of petrol was assumed to be phased in from 1996 to 2000, and to remain constant thereafter to the year 2015. Table 9.1 specifies the carbon tax levels analysed and their associated petrol prices, based on the assumption that fuel producers will pass all of the tax on to consumers in a highly competitive market.

Behavioural responses to petrol price increases by both consumers and vehicle manufacturers were analysed. Urban and non-urban road passenger travel were analysed separately. Responses to higher petrol prices by motorists in Sydney, Melbourne, Brisbane, Adelaide, Perth and Canberra were analysed using the ITS/BTCE model (appendix VI). Given a lack of data on non-urban responses to a carbon tax, the non-urban analysis was essentially an extrapolation of the urban results.

Basecase emissions were estimated using the BTCE CARMOD model of the Australian passenger vehicle fleet (appendix VII). Changes from the basecase due to imposition of various levels of carbon tax were estimated using the ITS/BTCE model, which simulates changes in urban passenger travel, including trips using light commercial vehicles, four-wheel drives, and people movers that are garaged at home, and public transport. It was assumed that public transport fares would not be affected, given high existing levels of subsidy. Because trips by road freight vehicles were taken as a constant background volume of traffic in the ITS/BTCE

TABLE 9.1 PETROL PRICES WITH VARIOUS CARBON TAX LEVELS[a,b]

(1995–96 cents / litre)

Carbon tax, year 2000 (1995–96 $/tonne carbon)[c]	*1996*	*1997*	*1998*	*1999*	*2000–2015*
$0 (basecase)	74.20	74.20	74.20	74.20	74.20
$100	75.43	76.66	77.90	79.13	80.36
$200	76.66	79.13	81.59	84.06	86.52
$300	77.90	81.59	85.29	88.98	92.68
$400	79.13	84.06	88.98	93.91	98.84
$500	80.36	86.52	92.68	98.84	105.00
$1000	86.52	98.84	111.16	123.48	135.80
$2000	98.84	123.48	148.12	172.76	197.40

a. It is assumed that the carbon tax is imposed on all fossil fuels in the economy, but only the effect on petrol price is considered in this table.

b. Petrol price for 1995–96 (basecase) was estimated by the BTCE before final data for the financial year became available.

c. To convert carbon taxes to 1995–96 $/tonne of CO_2, multiply the $/tonne carbon by 0.273 (based on atomic weight of 12 for carbon and 16 for oxygen).

Note A tax on the carbon content of petrol was assumed to be phased in from 1996 to 2000, and to remain constant thereafter to the year 2015.

Source BTCE estimates.

model, the effect on them of a carbon tax was not included in the analysis. Any changes in emissions from increased demand for urban public transport (UPT) were netted out in the calculation of emissions from the passenger vehicle sector.

In line with the partial equilibrium nature of the BTCE study, only the direct effects of the tax within the road passenger/UPT sector were considered. Feedback effects from the general economy in response to higher costs of passenger travel were not modelled.

Urban travel

Changes in emissions

Many facets of travel-related behaviour are simulated by the ITS/BTCE model. The behaviour modelled includes decisions by households in six capital cities regarding the number and type of vehicles in the household, distances travelled, departure times, mode choices for commuting, and residential and workplace location.

Simulations showed that very few commuters change residential location, job location or the number of vehicles in the household in response to increased petrol prices. There is some tendency to purchase smaller vehicles, but the major short-term response is a reduction in vehicle-kilometres travelled (VKT). The implicit short-term elasticity of petrol use to change in petrol price is about –0.1. In other words, a 10 per cent increase in the petrol price gives rise to a fairly immediate 1 per cent reduction in VKT and petrol use.

But over the longer term a carbon tax would result in an additional important effect—the response by vehicle manufacturers to increased demand for more fuel-efficient cars. Due to the time needed for redesign, any changes in fuel intensity in newly manufactured vehicles occur only about five years after changes in fuel prices (Greene 1990, p. 42). New, more fuel-efficient vehicles subsequently spread slowly through the fleet as older vehicles are scrapped. On the basis of Greene (1990, p. 55), it was assumed that the elasticity of the change in fuel intensity of new vehicles in response to a change in fuel price was –0.1. Table 9.2 specifies how the fuel intensities of new vehicles were assumed to change in response to petrol price changes. The new vehicle fuel intensities of table 9.2 were used in the analyses utilising the BTCE/ITS model.

The overall result of the model simulations and allowance for responses by vehicle manufacturers was an implicit long-run price elasticity for petrol use of about –0.2. That is, a 100 per cent increase in petrol prices (from 74.2 cents per litre to roughly $1.50) would, about 20 years after announcement, cause a 20 per cent reduction in annual petrol use.

The maximum petrol price simulated was $1.97 per litre. Because the ITS/BTCE model is based on stated preference surveys of households that have not experienced petrol prices of even this magnitude, any simulations of the model above this level could produce questionable results.

Prices of new vehicles were assumed to increase to cover the cost to manufacturers of the technology required to improve fuel intensity. Assumed increases in new vehicle prices were based on the relationship described in chapter 3, and are presented in table 9.3. As might be expected, new vehicle prices increase more quickly as taxes and fuel price increases become more extreme.

The ITS/BTCE model provides an estimate of changes in CO_2 emissions resulting from a change in VKT after imposition of the carbon tax.

TABLE 9.2 NEW CAR FUEL INTENSITIES WITH VARIOUS CARBON TAX LEVELS

(litres/100 km)

Carbon tax (1995–96 $/tonne carbon)[a]	*2001*	*2005*	*2010*	*2015*
$0 (basecase)	9.11	8.73	8.21	7.74
$100	9.04	8.66	8.14	7.68
$200	8.96	8.58	8.08	7.62
$300	8.88	8.51	8.01	7.55
$400	8.81	8.44	7.94	7.49
$500	8.73	8.37	7.87	7.42
$1000	8.35	8.00	7.53	7.10
$2000	7.60	7.28	6.85	6.46

a. To convert carbon taxes to 1995–96 $/tonne of CO_2, multiply the $/tonne carbon by 0.273 (based on atomic weight of 12 for carbon and 16 for oxygen).

Note The average new car fuel intensity in 1995–96 is about 10 litres per 100 kilometres. A tax on the carbon content of petrol was assumed to be phased in from 1996 to 2000, and to remain constant thereafter to the year 2015. A lag of five years in response by manufacturers has been assumed in determining changes in fuel intensities of new vehicles.

Source BTCE estimates based on Greene 1990, p. 55.

TABLE 9.3 INCREASES IN NEW CAR PRICES WITH VARIOUS CARBON TAX LEVELS

(per cent)

Carbon tax (1995–96 $/tonne carbon)[a]	*Price increase per vehicle*
$100	0.01
$200	0.03
$300	0.05
$400	0.08
$500	0.10
$1000	0.29
$2000	0.94

a. To convert carbon taxes to 1995–96 $/tonne of CO_2, multiply the $/tonne carbon by 0.273 (based on atomic weight of 12 for carbon and 16 for oxygen).

Source BTCE estimates (see chapter 3).

However it does not calculate emissions of non-CO_2 gases. Non-CO_2 greenhouse gas emissions (CH_4, N_2O, NO_x, CO, NMVOCs) were calculated using the CARMOD model. Once the change in VKT had been determined using the ITS/BTCE model, CARMOD provided estimates of emissions per VKT for each of the non-CO_2 gases. The emissions per VKT in CARMOD depend on several factors including the type of vehicle and driving conditions. Emissions per VKT vary over time, reflecting the gradual change in the composition of the urban passenger fleet over time.

Costs

The welfare cost to society of a carbon tax was calculated using the following disaggregation:

$$\text{Social cost} = \Delta\ \text{Government revenue} + \Delta\ \text{Consumer surplus} + \Delta\ \text{Producer surplus} + \Delta\ \text{Externalities}$$

where Δ stands for 'change in'.

Government revenue from a carbon tax (a transfer payment) is the mirror image of increased consumer cost. Government revenue includes increased collections from fuel excise, sales tax on new vehicles, road tolls, registration charges and carbon tax. Implementation costs of a carbon tax were assumed to be negligible. Administration of a carbon tax could be handled using existing arrangements for collection of fuel excise, at little additional cost.

Consumer surplus is a measure of the willingness to pay for a product or service beyond the price actually paid. If the retail price of petrol is 74.2 cents per litre (as assumed here) and a carbon tax raises its price to 80 cents, then those consumers who are not willing to pay the higher price but did purchase petrol before, will suffer a loss in consumer surplus. For each consumer, the loss in consumer surplus (for each litre no longer purchased) is equal to the difference in the post-tax price and the amount that they would have been willing to pay before the tax. A loss in consumer surplus is sometimes characterised as an 'inconvenience' to a consumer, and could be thought of as the 'political pain' due to imposition of an abatement measure such as a carbon tax. The concept of consumer surplus is explained more fully in elementary texts such as McCloskey (1985, pp. 196–221).

In reality, consumers faced with increased fuel prices could choose to react in a range of ways, including making no changes to travel behaviour and paying the higher (post-tax) price, to driving a little less and occasionally taking public transport, through to long-run responses such as moving closer to work, or selling the car and walking to work. Estimating a loss in consumer surplus becomes extremely complex against a background of such real life choices.

The ITS/BTCE model is designed specifically to capture real life complexities of choice. However, the results from the model indicated that most commuters would react by reducing the amount of car travel undertaken. Few drivers changed residential location, job location or the number of vehicles in the household (although there was some tendency for new sales to be in the smaller engine size categories). Losses in consumer surplus can therefore be estimated without significant loss of accuracy solely on the basis of tax-related changes in the car travel (VKT) ‘market’.

Car travel ‘market’ costs are an aggregation of all passenger vehicle-related costs and are the sum of the following:

- fuel costs (based on the retail price of petrol, including fuel excise and any additional carbon tax);
- parking (for commuter travel only);
- any road tolls incurred, such as over the Sydney Harbour Bridge;
- for commuters travelling by passenger vehicle, the value to them of time spent travelling **(appendix table XIII.2)**.

Average travel costs were estimated by dividing aggregated travel costs in each city by aggregate VKT travelled in that city.

In the case of travel by car that is still undertaken in the presence of a carbon tax, the loss in consumer surplus is equal to the extra cost of this travel. The cost of travel increases immediately due to increased petrol prices, but decreases in the longer term due to increased average fleet fuel efficiency as people switch to smaller cars and as more fuel-efficient vehicles are produced. Individual travel costs will also be affected by any consequential lower expenditure on parking and road tolls, as people switch to public transport.

For car travel no longer undertaken, the maximum benefit forgone is the extra amount of carbon tax paid. Half of the increase in costs due to the carbon tax was used as a measure of the average loss in consumer surplus from decreased car travel.

Producers (in this case the oil companies) bear a cost in lost profit on fuel sales. This loss was assumed equal to 2 per cent of the retail price of the fuel saved (PSA 1995, p. 52, and Australian Institute of Petroleum, pers. comm. 20 February 1996).

Account was also taken of changes in three externalities associated with changes in carbon tax levels: the environmental effects of noxious emissions, accidents, and urban traffic congestion. Appendix X presents estimates of environmental costs of noxious emissions. Reductions in emissions of CO, NO_x and NMVOCs would generate commensurate benefits of about 0.11 cents per kilometre, averaged over rural and urban areas. Reduced accident costs due to the decreased amount of travel caused by a carbon tax are based on an estimate of 4 cents per vehicle-kilometre (BTCE 1995h, p. 2 and 1996a, p. 94). **Appendix XIII** details the benefits of reduced urban congestion.

Non-urban travel

The six cities included in the ITS/BTCE model represent about 50 per cent of total Australian passenger vehicle travel, and hence of greenhouse gas emissions. Reductions in car travel and emissions for other cities and towns and rural residents were estimated through extrapolation of the results for the six metropolitan centres. The extrapolation was based on the assumption that the main factors affecting emissions—percentage changes in the amount travelled and the fuel intensities of new vehicles—would be similar for urban and rural drivers. The BTCE had no way of validating this assumption.

RESULTS

All results were aggregated across the six capital cities and non-urban areas to give an aggregate Australian estimate for changes in emissions. Unless noted otherwise, no significant differences in behavioural effects were evident in the results for individual cities.

ITS/BTCE model simulations showed very little change in residential location, job location or in the number of vehicles per household in response to increased petrol prices. At the maximum tax level of $2000 per tonne of carbon, small cars increased their share of total sales by about 2.5 per cent, and UPT captured an extra 3.5 per cent share of total travel (won from driving). But the main effects were the reduction in VKT (responsible for a 9 per cent reduction in annual CO_2 equivalent emissions by 2015) and the longer-term response of car manufacturers (responsible for an equal reduction by 2015). By 2015, about 18 per cent of the 23.1 per cent reduction in annual CO_2 equivalent emissions was attributable to these two effects.

Table 9.4 shows reductions in cumulative greenhouse gas emissions for all levels of the carbon tax. Assessed at 2015, the cumulative emission reductions due to a carbon tax are significant at the high tax levels. While reductions increase with higher taxes, they are not directly proportional to the tax. For example, reductions at the $1000 per tonne tax level are generally less than ten times the reductions at the $100 per tonne of carbon level.

Table 9.5 shows the change between the tax simulations and the basecase in each year for CO_2 emissions, non-CO_2 emissions and VKT. The three tax intensities presented illustrate the trends common to all tax levels analysed. The reduction in CO_2 increases steadily over time. From 1996 to 2000, the increased change is driven by increasing tax levels (table 9.1). During this period, decreased travel causes most of the CO_2 reduction. This result can be seen by noting the similarity between the change in VKT and the change in CO_2 change. By 2000, vehicle

TABLE 9.4 REDUCTIONS IN CUMULATIVE GREENHOUSE GAS EMISSIONS FROM CAR TRAVEL DUE TO CARBON TAX

(million tonnes of CO_2 equivalent)

Carbon tax (1995–96 $/tonne carbon)[a]	*1996 to 2000*	*1996 to 2005*	*1996 to 2010*	*1996 to 2015*
$100	1.31	3.79	6.70	10.01
$200	2.57	7.37	13.04	19.49
$300	3.76	10.78	19.04	28.44
$400	4.92	14.05	24.82	37.05
$500	6.06	17.28	30.60	45.80
$1000	11.20	31.69	56.19	84.18
$2000	20.00	56.26	99.92	149.54

a. To convert carbon taxes to 1995–96 $/tonne of CO_2, multiply the $/tonne carbon by 0.273 (based on atomic weight of 12 for carbon and 16 for oxygen).

Note Reductions are measured against basecase emission levels for cars given in appendix III.

Source BTCE estimates.

TABLE 9.5 CHANGE IN ANNUAL CO_2 EMISSIONS, NON-CO_2 EMISSIONS[a] AND VEHICLE-KILOMETRES TRAVELLED[b] AT THREE REPRESENTATIVE CARBON TAX LEVELS, 1996–2015

(per cent)

	$500/tonne carbon			$1000/tonne carbon			$2000/tonne carbon		
Year	*CO_2*	*non-CO_2*	*VKT*	*CO_2*	*non-CO_2*	*VKT*	*CO_2*	*non-CO_2*	*VKT*
1996	–0.9	–0.9	–0.9	–1.8	–1.6	–1.6	–3.5	–3.1	–3.1
1997	–1.8	–1.6	–1.6	–3.5	–3.1	–3.1	–6.3	–5.7	–5.7
1998	–2.6	–2.4	–2.4	–4.9	–4.4	–4.4	–8.8	–7.8	–7.8
1999	–3.4	–3.1	–3.1	–6.2	–5.6	–5.6	–11.0	–9.8	–9.8
2000	–4.1	–3.7	–3.7	–7.5	–6.7	–6.7	–13.1	–11.6	–11.6
2001	–4.4	–3.7	–3.7	–8.0	–6.6	–6.6	–14.1	–11.4	–11.4
2002	–4.6	–3.6	–3.6	–8.3	–6.5	–6.5	–14.8	–11.2	–11.2
2003	–4.8	–3.6	–3.6	–8.7	–6.4	–6.4	–15.6	–11.0	–11.0
2004	–4.9	–3.6	–3.6	–9.1	–6.4	–6.4	–16.2	–10.8	–10.8
2005	–5.1	–3.5	–3.5	–9.4	–6.3	–6.3	–16.9	–10.6	–10.6
2006	–5.3	–3.5	–3.5	–9.8	–6.2	–6.2	–17.7	–10.4	–10.4
2007	–5.5	–3.5	–3.5	–10.1	–6.1	–6.1	–18.2	–10.3	–10.3
2008	–5.7	–3.4	–3.4	–10.5	–6.1	–6.1	–18.8	–10.1	–10.1
2009	–5.8	–3.4	–3.4	–10.8	–6.0	–6.0	–19.4	–9.9	–9.9
2010	–6.0	–3.4	–3.4	–11.2	–5.9	–5.9	–20.1	–9.8	–9.8
2011	–6.3	–3.4	–3.4	–11.6	–5.9	–5.9	–20.7	–9.6	–9.6
2012	–6.4	–3.3	–3.3	–11.9	–5.8	–5.8	–21.3	–9.5	–9.5
2013	–6.6	–3.3	–3.3	–12.3	–5.7	–5.7	–21.9	–9.3	–9.3
2014	–6.8	–3.2	–3.2	–12.6	–5.7	–5.7	–22.5	–9.2	–9.2
2015	–7.0	–3.2	–3.2	–12.9	–5.6	–5.6	–23.1	–9.0	–9.0

a. Non-CO_2 emissions refers to NO_x, CO, NMVOCs, N_2O and CH_4.

b. VKT = vehicle-kilometres travelled by passenger vehicles.

Note To convert carbon taxes to 1995–96 $/tonne of CO_2, multiply the $/tonne carbon by 0.273 (based on atomic weight of 12 for carbon and 16 for oxygen).

Source BTCE estimates.

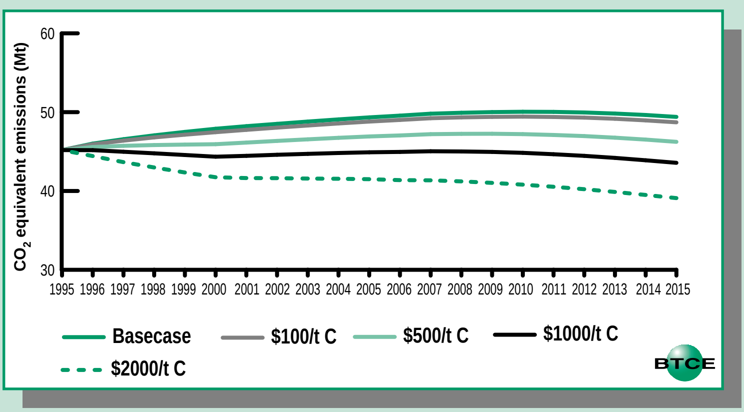
manufacturers are assumed to begin to produce more efficient vehicles. As these vehicles penetrate the fleet, the CO_2 reduction continues to increase. The VKT change remains constant or even decreases from 2000 to 2015, because tax levels remain constant while more efficient vehicles encourage people to drive somewhat more. By 2015, decreased travel accounts for only about half the change in CO_2 emissions, with vehicle fuel intensity improvements accounting for most of the remainder. Minor emission reductions are contributed by downsizing of vehicles purchased and mode shifting from cars to urban public transport.

Table 9.5 also shows that the non-CO_2 emissions change in direct proportion to the VKT change. This result reflects the modelling assumption that non-CO_2 emissions per VKT will not be affected to any additional extent beyond the reduction in fuel used. Total greenhouse emissions from car travel are dominated by CO_2; in 1993 CO_2 emissions were about 82 per cent of total car greenhouse emissions (BTCE 1995c, p. 214).

Figure 9.2 shows annual greenhouse gas emissions to 2015 from car travel, for various carbon tax levels. The four tax levels shown illustrate the overall changes. Emissions under the $200, $300 and $400 taxes behaved as expected, with curves lying between the $100 and $500 tax curves.

Present values (1995–96 $ million) of the social costs of the carbon tax are given in table 9.6. Costs increase at higher tax levels, with proportional cost increases exceeding increases in tax levels. For the $100 to $500 per tonne taxes, the cumulative costs from 1996 to 2015 are smaller than the cumulative costs from 1996 to 2010.

FIGURE 9.2 ANNUAL GREENHOUSE GAS EMISSIONS FROM CAR TRAVEL WITH VARIOUS CARBON TAX LEVELS



Source BTCE estimates.

TABLE 9.6 CARBON TAX ON PETROL: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Carbon tax	*Cumulative reduction: CO_2 equivalent*	*Change in cumulative reduction: CO_2 equivalent*	*Social cost of cumulative reduction*	*Change in social cost*	*Average social cost[c]*	*Marginal social cost[d]*
(1995–96 $/tonne carbon)[b]	*(million tonnes)*	*(million tonnes)*	*($ million)*	*($ million)*	*($ per tonne)*	*($ per tonne)*
1996 to 2000						
$100	1.31	1.31	–159	–159	–121	–121
$200	2.57	1.26	–280	–121	–109	–96
$300	3.76	1.19	–383	–103	–102	–87
$400	4.92	1.16	–468	–85	–95	–73
$500	6.06	1.14	–539	–71	–89	–62
$1000	11.20	5.14	–663	–124	–59	–24
$2000	20.00	8.80	–73	590	–4	67
1996 to 2005						
$100	3.79	3.79	–376	–376	–99	–99
$200	7.37	3.58	–659	–283	–89	–79
$300	10.78	3.41	–894	–235	–83	–69
$400	14.05	3.27	–1 082	–188	–77	–57
$500	17.28	3.23	–1 233	–151	–71	–47
$1000	31.69	14.41	–1 433	–200	–45	–14
$2000	56.26	24.57	113	1 546	2	63
1996 to 2010						
$100	6.70	6.70	–544	–544	–81	–81
$200	13.04	6.34	–956	–412	–73	–65
$300	19.04	6.00	–1 297	–341	–68	–57
$400	24.82	5.78	–1 573	–276	–63	–48
$500	30.60	5.78	–1 796	–223	–59	–39
$1000	56.19	25.59	–2 139	–343	–38	–13
$2000	99.92	43.73	–168	1 971	–2	45
1996 to 2015						
$100	10.01	10.01	–674	–674	–67	–67
$200	19.49	9.48	–1 190	–516	–61	–54
$300	28.44	8.95	–1 622	–432	–57	–48
$400	37.05	8.61	–1 975	–353	–53	–41
$500	45.80	8.75	–2 269	–294	–50	–34
$1000	84.18	38.38	–2 819	–550	–33	–14
$2000	149.54	65.36	–874	1 945	–6	30

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. To convert carbon taxes to 1995–96 $/tonne of CO_2, multiply the $/tonne carbon by 0.273 (based on atomic weight of 12 for carbon and 16 for oxygen).

c. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

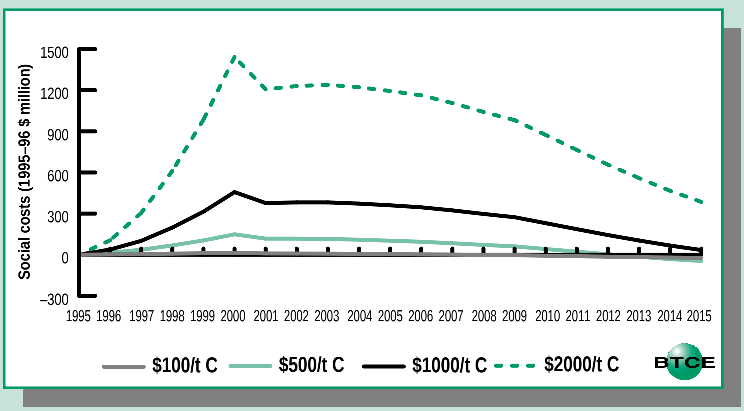
d. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates.

This counterintuitive result arises because in later years of low tax levels the costs are negative—the carbon tax produces a net benefit to society. The social benefit is a combination of the decreased use of fuel due to the induced demand for more fuel-efficient vehicles, and to the decreased costs of congestion, accidents and health problems as a result of decreased travel. Because of the uncertainties involved in establishing a value for travel time **(appendix XIII)**, the estimated value of benefits gained from reduced congestion needs to be treated with due caution.

Annual costs of four representative carbon tax levels are illustrated in figure 9.3. Costs increase from 1996 to 2000 as motorists reduce the amount that they travel. This decrease in car travel results in loss of consumer surplus plus loss in fuel excise for the government. Carbon tax receipts are transferred from motorists to the government and are therefore a transfer payment with no net cost to society as a whole. Benefits from reduced congestion, accidents and health problems are small in relation to the other costs in the period 1996–2000. From 2001, the tax and associated travel changes remain constant but more fuel-efficient vehicles start to enter the Australian car fleet. The benefits of the more efficient vehicles produce an immediate fall in costs, which continue to decline to 2015, as well as some rebound in VKT as cars become cheaper to run. Figure 9.3 shows that annual costs for the $100 and $500 tax intensities become negative by 2015.

FIGURE 9.3 ADDITIONAL ANNUAL COSTS OF CAR TRAVEL AT VARIOUS LEVELS OF CARBON TAX



Note Value of costs (1995–96 $) estimated using a 10 per cent discount rate.

Source BTCE estimates.

Figure 9.1 shows marginal cost curves for the periods 1996–2000, 1996–2005, 1996–2010 and 1996–2015 respectively. As expected from the results discussed in this section, marginal costs increase with higher tax levels and decrease over time. Table 9.6 shows the total net present values of social costs, cumulative emission reductions and average and marginal costs, for the years from 1996 through to 2000, 2005, 2010 and 2015 respectively.

Table 9.7 shows the annual carbon tax revenue derived from cars. At low levels of the tax there is a lower revenue that shows some growth

TABLE 9.7 ANNUAL CARBON TAX REVENUE FROM CAR TRAVEL

(1995–96 $ million)

Financial year	Carbon tax (1995–96 $/tonne carbon)[a]						
	$100	*$200*	*$300*	*$400*	*$500*	*$1000*	*$2000*
1996	215	429	642	854	1 065	2 112	4 152
1997	436	870	1 300	1 727	2 151	4 229	8 202
1998	664	1 321	1 972	2 615	3 252	6 351	12 171
1999	897	1 782	2 654	3 515	4 365	8 471	16 059
2000	1 135	2 249	3 346	4 425	5 488	10 585	19 860
2001	1 147	2 272	3 378	4 466	5 535	10 649	19 856
2002	1 158	2 293	3 408	4 504	5 580	10 714	19 894
2003	1 168	2 313	3 436	4 539	5 621	10 769	19 904
2004	1 178	2 331	3 461	4 571	5 658	10 819	19 916
2005	1 187	2 348	3 485	4 600	5 692	10 861	19 910
2006	1 194	2 361	3 504	4 624	5 718	10 889	19 863
2007	1 200	2 372	3 519	4 642	5 738	10 908	19 835
2008	1 204	2 380	3 529	4 654	5 751	10 912	19 775
2009	1 207	2 385	3 535	4 661	5 756	10 903	19 678
2010	1 208	2 386	3 536	4 659	5 751	10 870	19 550
2011	1 208	2 384	3 531	4 651	5 739	10 824	19 397
2012	1 206	2 379	3 522	4 638	5 719	10 765	19 220
2013	1 202	2 370	3 508	4 618	5 692	10 693	19 019
2014	1 196	2 359	3 490	4 592	5 657	10 608	18 798
2015	1 189	2 344	3 466	4 560	5 616	10 512	18 562

a. To convert carbon taxes to 1995–96 $/tonne of CO_2, multiply the $/tonne carbon by 0.273 (based on atomic weight of 12 for carbon and 16 for oxygen).

Note Revenues are in addition to fuel excises as at June 1996.

Source BTCE estimates.

over time. At high levels of a carbon tax, initially high revenues shrink over time as newer, more fuel-efficient cars are purchased and permeate the fleet.

Sensitivity testing

The sensitivity of the costs of a carbon tax measure to different discount rates is shown in table 9.8. For taxes from $200 to $2000 per tonne of carbon, a higher discount rate reduces the present value of future costs, thus reducing the present value of the social cost of the tax, and vice versa for a lower discount rate.

The $100 tax level shows the opposite trend: higher costs for a high discount rate, and lower costs for a low discount rate. Negative costs in the later years of this tax level cause the strange result. At the 5 per cent discount rate, costs in later years have a stronger weighting than at the 10 per cent discount rate. The negative costs involved therefore have a proportionately higher influence on total cumulative costs. The opposite effect occurs at the 15 per cent discount rate.

EQUITY ISSUES

Costs for consumers (car owners), government, producers (fuel sellers), and externalities are shown in table 9.9. The largest effect is the carbon tax revenue which is transferred to the government (benefiting mainly taxpayers, many of whom are also motorists). However, the effect of externalities (in this case a social benefit) is also substantial. About two-thirds of the externalities benefit comes from reduced congestion, with reduced accident costs accounting for most of the remainder. As Australian cities become increasingly congested over the next 20 years, any greenhouse measure that restricts demand for car travel (like a carbon tax) will produce significant externalities benefits. In contrast, the measure to increase the fuel efficiency of vehicles, reviewed in chapter 3, increased the demand for travel and so produced substantial additional social costs by adding to already bad congestion.

Figure 9.4 shows the extra percentage of income spent on fuel by household income class with various levels of carbon tax. The tax is generally regressive in terms of income, as are all consumption-based taxes.

TABLE 9.8 TOTAL SOCIAL COSTS OF CARBON TAX FOR CAR TRAVEL USING VARIOUS DISCOUNT RATES, 1996 TO 2015

(1995–96 $ million)

Carbon tax (1995–95 $/tonne carbon)[a]	Discount rate (per cent) 5	10	15
$100	–1 058	–674	–463
$200	–1 871	–1 190	–816
$300	–2 554	–1 622	–1 112
$400	–3 116	–1 975	–1 353
$500	–3 586	–2 269	–1 552
$1000	–4 533	–2 819	–1 908
$2000	–1 859	–874	–455

a. To convert carbon taxes to 1995–96 $/tonne of CO_2, multiply the $/tonne carbon by 0.273 (based on atomic weight of 12 for carbon and 16 for oxygen).

Source BTCE estimates.

TABLE 9.9 COMPOSITION OF TOTAL SOCIAL COSTS[a] OF CARBON TAX IN 2015

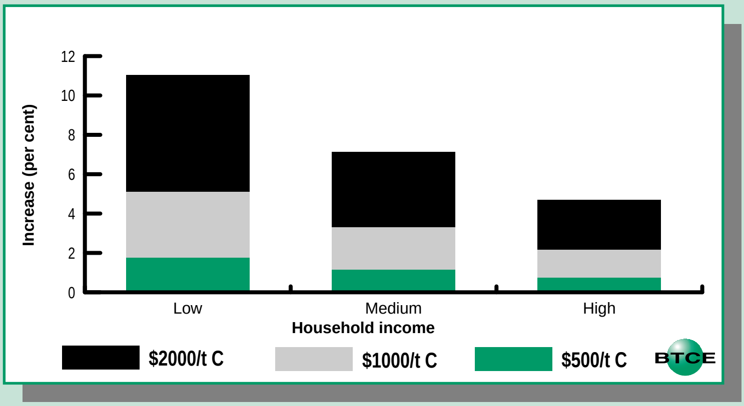
(1995–96 $ million)

Carbon tax (1995–96 $/tonne carbon)[b]	Consumers	Government	Producers	Externalities
$100	7 991.5	–7 530.5	31	–1 166
$200	15 887.5	–14 934.5	119	–2 262
$300	23 700.8	–22 223.8	193	–3 292
$400	31 430.3	–29 399.3	264	–4 270
$500	39 022.1	–36 426.1	335	–5 200
$1000	75 944.5	–70 101.5	651	–9 313
$2000	144 264.4	–130 338.4	1 115	–15 915

a. Net present values; 10 per cent discount rate used.

b. To convert carbon taxes to 1995–96 $/tonne of CO_2, multiply the $/tonne carbon by 0.273 (based on atomic weight of 12 for carbon and 16 for oxygen).

FIGURE 9.4 EXTRA PERCENTAGE OF INCOME SPENT ON TAXED PETROL, BY HOUSEHOLD INCOME



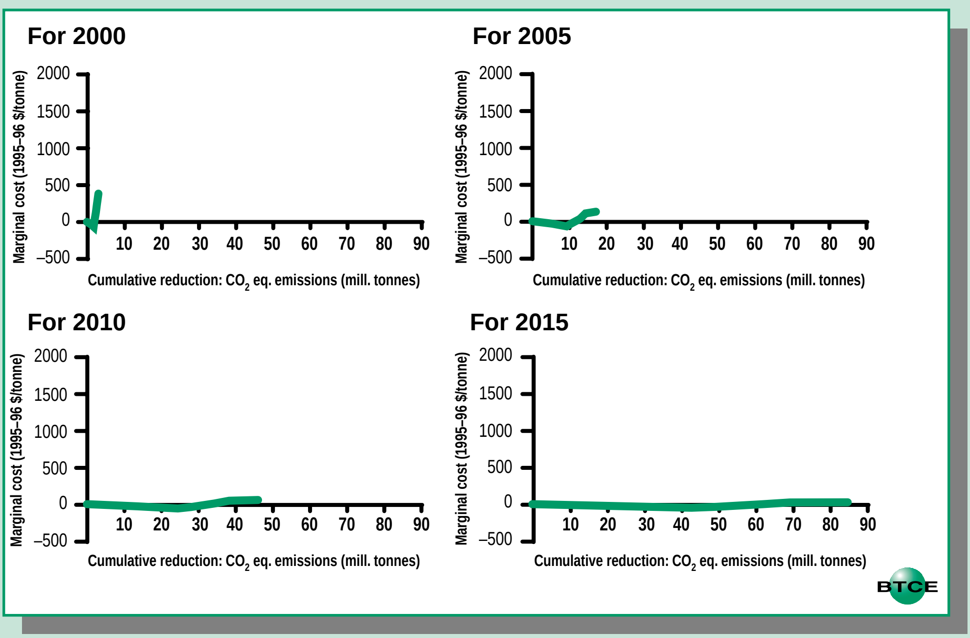
Source Based on a survey conducted by the Institute of Transport Studies, Graduate School of Business, The University of Sydney under contract to the BTCE.

...AT A GLANCE

Advances in technology can reduce greenhouse gas emissions, without the cost of forgoing transport activity. Accelerated introduction of currently proven technology enhancements that increase the fuel efficiency of road freight vehicles would achieve a cumulative reduction of 18 per cent in greenhouse gas emissions by 2015 compared with basecase levels for road freight. Introduction of some of the technologies analysed in this chapter would represent a 'no regrets' measure.

- Commercial vehicles are currently responsible for about 28 per cent of the transport sector's greenhouse gas emissions from energy use, but this share will increase to about 39 per cent by 2015 if no action is taken ('business as usual' scenario).
- Technological developments considered consist of incremental improvements to existing technology that are commercially feasible within the next twenty years.
- Changes in greenhouse gas emissions resulting from accelerated uptake of more fuel-efficient technology are estimated using TRUCKMOD, a model of the Australian commercial vehicle fleet developed by the BTCE.
- Costs will be lower over the long term compared with the short term. However, it is highly likely that costs presented have been significantly underestimated. Increased vehicle costs would be offset to some extent by a reduction in fuel costs per kilometre.

FIGURE 10.1 FUEL SAVING TECHNOLOGY FOR ROAD FREIGHT VEHICLES: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 10 ACCELERATED UPTAKE OF FUEL SAVING TECHNOLOGY FOR ROAD FREIGHT VEHICLES

Internal combustion engines convert energy released from the combustion of fossil fuels into motive power. But not all the energy released upon combustion is converted into movement of the vehicle. Some of the energy is used to overcome resistance forces acting on various parts of the vehicle and some of the energy is lost as heat.

Apart from moving the vehicle, the main areas where energy from combustion is used up include:

- Braking—the energy of forward momentum is converted to heat in the brakes. This heat energy is in turn lost to the atmosphere.
- Aerodynamic drag—a resistance force acting on a moving vehicle's surface area. It is a function of wind intensity and direction and a vehicle's frontal area and body shape. The power required to overcome aerodynamic drag is a cubic function of a vehicle's speed through the air. Aerodynamic drag is thus minimal at low speeds but a large proportion of the total resistance forces acting on the vehicle at high speeds (Randall 1991, p. 42; Nelson English, Loxton & Andrews 1991b, p. 25).
- Transmission losses—the transmission system transfers the energy generated by the engine to the road wheels. The transmission system may include clutch, gearbox, drive shaft and final drive, depending on the design. The transmission system, amongst other things, must allow for disconnection of the engine from the driving wheels, connection with the driving wheels to be made smoothly, and enable the leverage between the engine and driving wheels to be varied.

- Engine friction and heat loss—frictional forces between moving parts in the engine result in some of the energy from combustion being lost as heat. The thermodynamic efficiency of the engine itself is also a consideration as a large proportion of the energy from combustion goes towards heating the engine surrounds.
- Rolling resistance—the total of all forces that tend to slow down a moving vehicle, including friction within the axles and transmission, wheel-bearing friction and friction between the road and the tyres.
- Accessories—the alternator, water pump, oil pump and air-conditioner are all powered by energy derived from the engine.

One way to improve the fuel efficiency of vehicles, and reduce the rate of greenhouse gas emissions, is to reduce these ancillary energy losses. The vehicle technology enhancements considered in this chapter, with the exception of regenerative braking, reduce such energy losses.

METHODOLOGY

The technological developments analysed are largely incremental improvements to existing vehicle technology that are considered commercially feasible within the next twenty years. More radical technological options that were not considered feasible for large scale manufacture by 2015, such as electric vehicles and hydrogen powered vehicles, were not analysed.

The BTCE does not claim specific expertise in the area of automotive engineering. Consequently, the individual technology options considered here include only those identified in the motor vehicle engineering literature, road freight trade publications and in discussions with industry sources. Where possible, optimistic estimates of the impact of each technology on fuel efficiency have been used to demonstrate the maximum potential reduction in emissions.

Petrol powered light commercial vehicles (LCVs)

For petrol powered LCVs, the technology enhancements evaluated in this study are based largely on the enhancements described in Nelson English, Loxton & Andrews (1991a, 1991b) and include the following:

- Enhancements in vehicle design to reduce aerodynamic drag.

- Weight reduction—using lighter materials for body parts. The scope for weight reduction in LCVs is limited by their load carrying requirements.
- Low friction and low mass squeezed cast aluminium pistons and rings, lightweight valves, titanium springs, and improved control of bore and piston dimensions to reduce mechanical and aerodynamic engine friction.
- Roller cam followers—use of a roller bearing for the camshaft control surface instead of a sliding contact, to reduce mechanical engine friction.
- Replacement of two-valve per cylinder overhead camshaft engines with equal performance four-valve per cylinder engines which offer improved thermodynamic efficiency due to a more compact combustion chamber and centrally placed spark plug. Central spark plug location and improved combustion chamber airflow characteristics allow the use of higher compression ratios. Pumping losses are reduced because of smaller displacement and larger valve area.
- Variable valve timing can vary intake valve timing and lift to match engine speed and load requirement, thereby reducing pumping losses.
- Multi-point fuel injection through use of one fuel injector per cylinder allows more precise fuel metering to each cylinder.
- Four/five speed automatic allows the engine to operate at closer to the most fuel-efficient point under all operating conditions.
- Continuously variable transmission (CVT) extends the concept of more gears to an infinite selection of gears. Current designs are torque-limited and can be employed only in small cars. Application to LCVs is limited by the load under which LCVs must operate.
- Electronic transmission control can be used to integrate engine operating information with vehicle speed information to select the optimum gear for best fuel economy.
- Lower viscosity (10W-30) oil reduces engine friction.
- Largely evolutionary improvements in tyres that reduce tyre rolling resistance.

- Evolutionary improvements to alternator, water pump, oil pump, and air-conditioning units to reduce the demand on engine energy output.

Diesel powered LCVs, rigid trucks and articulated trucks

For diesel powered vehicles, the technology enhancements evaluated in this study are:

- Aerodynamic enhancements to vehicle design to reduce aerodynamic drag.
- Electronic fuel injection control to vary fuel injection to match engine speed and load conditions.
- High pressure fuel injection which increases the contact of fuel with the heated air in the combustion chamber, increasing the efficiency of fuel burn.
- Supercharging or turbocharging. A supercharger is an engine-driven compressor that forces the air–fuel mixture into the cylinders at higher than atmospheric pressure, enabling a greater amount of the air–fuel mixture to enter the combustion chamber and increasing the efficiency of the engine. A turbocharger is an exhaust gas turbine driven compressor that performs the same function as the supercharger.
- Intercooling increases the volumetric efficiency of the engine by increasing the density of the air before it is delivered to the combustion chamber.
- Turbo-compounding—an exhaust gas driven turbine connected to the crankshaft and used to propel the vehicle.
- High temperature insulation for engines (and use of ceramic materials). It has been shown that high surface temperatures of combustion chamber walls cause a significant drop in volumetric efficiency. Substantial fuel efficiency gains can be realised if the engine walls are insulated to reduce heat absorption (Assanis & Heywood 1987, p. 283).
- Low-heat-rejection engines (also referred to as ‘adiabatic’ engines) offer even greater potential to improve the volumetric efficiency of engines and reduce fuel consumption.
- Improved tyres can reduce rolling resistance.

The size of the overall fuel efficiency improvement resulting from adoption of these technologies will depend on both the rate of penetration of technology enhancements in the vehicle fleet, and the size of the fuel efficiency improvement resulting from individual technology enhancements.

Where possible, estimates of the size of fuel efficiency improvements are based on published results from overseas studies of advanced technology uptake. Where data were not available, the BTCE relied on reasonable assumptions.

Current vehicle penetration rates are based on a survey of the trade literature (*Truck and Bus Transportation* 1993, 1994, 1995a), which provides details of specifications of currently manufactured vehicles. Estimates of future penetration rates are largely based on the assumption that most of the technology advances considered in this study will be standard in new vehicles by 2015 at the latest.

The assumed penetration rates and the technology-specific individual vehicle fuel efficiency improvements for each technology option are listed in tables 10.1 to 10.4.

Estimates of fuel efficiency improvement under the basecase and under the accelerated technology implementation scenarios

Changes in greenhouse emissions due to accelerated uptake of more fuel-efficient technology were estimated using TRUCKMOD (appendix VIII), a model of the Australian commercial vehicle fleet developed by the BTCE. TRUCKMOD relies on the average vintage-specific fuel intensity of new road freight vehicles to calculate changes in emissions.

Fuel intensity improvements resulting from each of the individual technology options were weighted by their expected future penetration rates and summed to give an average new vehicle fuel efficiency improvement. The fuel intensity improvements set out in tables 10.1 to 10.4 are therefore estimates of the basecase average new vehicle fuel intensity improvement.

A second set of results was generated using TRUCKMOD to estimate CO_2 equivalent emissions under the accelerated technology implementation scenarios. The assumptions made about accelerated introduction of more advanced technology are also listed in tables 10.1 to 10.4. Average new vehicle fuel intensities for each of LCVs, rigid trucks

TABLE 10.1 TECHNOLOGY ENHANCEMENTS FOR PETROL POWERED LIGHT COMMERCIAL VEHICLES

Technology option	*Fuel efficiency improvement (per cent/vehicle)*	*Technology penetration base rate (per cent)*	*Assumed technology penetration rate[a]: basecase (per cent)*			*Assumed technology penetration rate[a]: accelerated technology scenario (per cent)*		
		1995	*2005*	*2010*	*2015*	*2005*	*2010*	*2015*
Aerodynamic improvement: drag reduction	2.3	20.0	50.0	100.0	100.0	80.0	100.0	100.0
4-speed automatic[b]	4.5	54.5	60.0	100.0	100.0	100.0	100.0	100.0
Torque converter lock-up	3.0	58.5	62.5	100.0	100.0	100.0	100.0	100.0
Electronic transmission control	0.5	12.0	46.0	100.0	100.0	100.0	100.0	100.0
Accessory improvements	0.5	..	68.0	100.0	100.0	100.0	100.0	100.0
Roller cam followers	2.0	19.0	46.0	100.0	100.0	100.0	100.0	100.0
Low friction piston/rings	2.0	48.5	83.0	100.0	100.0	100.0	100.0	100.0
10W-30 oil	0.5	0.0	66.0	100.0	100.0	100.0	100.0	100.0
Tyre improvements	0.5	..	68.0	100.0	100.0	100.0	100.0	100.0
4-valve engines	5.0	33.3	53.8	100.0	100.0	100.0	100.0	100.0
Multi-point fuel injection (additional gain over CFI)[c]	3.0	66.3	79.8	100.0	100.0	100.0	100.0	100.0
Central fuel injection[c]	3.0	10.9	16.9	100.0	100.0	100.0	100.0	100.0
Front wheel drive	1.5	80.0	100.0	100.0	100.0	100.0	100.0	100.0
5-speed automatic (additional gain over 4-speed automatic)[b]	2.5	0.0	20.0	20.0	20.0	100.0	100.0	100.0

Continued on next page

TABLE 10.1 TECHNOLOGY ENHANCEMENTS FOR PETROL POWERED LIGHT COMMERCIAL VEHICLES (continued)

Technology option	*Fuel efficiency improvement (per cent/vehicle)*	*Technology penetration base rate (per cent)*	*Assumed technology penetration rate[a]: basecase (per cent)*			*Assumed technology penetration rate[a]: accelerated technology scenario (per cent)*		
		1995	*2005*	*2010*	*2015*	*2005*	*2010*	*2015*
Variable valve timing	3.0	0.0	30.0	80.0	100.0	100.0	100.0	100.0
Electric power steering	1.0	0.0	20.0	80.0	80.0	100.0	100.0	100.0
CVT (additional gain over 5-speed automatic)[b]	1.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0
Weight reduction (increase)	–5.0	..	33.0	33.0	33.0	40.0	50.0	50.0
Performance increase	–2.2	..	54.0	54.0	54.0	0.0	0.0	0.0

.. Not applicable

a. Unless otherwise stated all penetration rate estimates are based on BTCE assumptions.

b. Mutually exclusive transmission systems. Based on Nelson English, Loxton & Andrews (1991, p. 41) assumption for passenger cars.

c. The effects of the central fuel injection and multi-point fuel injection are additive in this spreadsheet and are based on Nelson English, Loxton & Andrews (1991, p. 41) assumption, but adjusted because of assumed differences between LCVs and passenger cars.

Source Nelson English, Loxton & Andrews 1991, table 4.4, p. 41.

TABLE 10.2 TECHNOLOGY ENHANCEMENTS FOR DIESEL POWERED LIGHT COMMERCIAL VEHICLES

Technology option	*Fuel efficiency improvement (per cent/vehicle)*	*Technology penetration base rate (per cent)*	*Assumed technology penetration rate[a]: basecase (per cent)*			*Assumed technology penetration rate[a]: accelerated technology scenario (per cent)*		
		1995	*2005*	*2010*	*2015*	*2005*	*2010*	*2015*
Supercharging/turbocharging[b]	7.0	35.0	50.0	75.0	75.0	100.0	100.0	100.0
High pressure fuel injection[b]	10.0	0.0	20.0	20.0	20.0	100.0	100.0	100.0
Electronic fuel injection control[b]	10.0	50.0	75.0	100.0	100.0	100.0	100.0	100.0
Aerodynamic enhancements	4.0	35.0	65.0	65.0	65.0	65.0	100.0	100.0
Low-heat-rejection (adiabatic) engines	6.0	0.0	0.0	20.0	50.0	50.0	100.0	100.0
Turbo-compounding	4.0	0.0	20.0	20.0	20.0	75.0	100.0	100.0
Intercooled engines	4.0	50.0	52.5	52.5	52.5	100.0	100.0	100.0
High temperature insulation (e.g. use of ceramics)	2.0	0.0	5.0	5.0	5.0	50.0	100.0	100.0
Tyres	2.0	0.0	50.0	75.0	100.0	100.0	100.0	100.0
Weight reduction (increase)	–5.0	..	33.0	33.0	33.0	40.0	50.0	50.0

.. Not applicable

a. Unless otherwise stated all penetration rate estimates are based on BTCE assumptions.

b. Brosthaus (1991).

Source BTCE estimates.

TABLE 10.3 TECHNOLOGY ENHANCEMENTS FOR DIESEL POWERED RIGID TRUCKS

	Fuel efficiency improvement (per cent/vehicle)	*Technology penetration base rate (per cent)*	*Assumed technology penetration rate[a]: basecase (per cent)*			*Assumed technology penetration rate[a]: accelerated technology scenario (per cent)*		
Technology option		*1995*	*2005*	*2010*	*2015*	*2005*	*2010*	*2015*
Supercharging/turbocharging[b]	6.0	30.0	80.0	80.0	80.0	100.0	100.0	100.0
High pressure fuel injection[b]	10.0	0.0	20.0	50.0	50.0	100.0	100.0	100.0
Electronic fuel injection control[b]	10.0	50.0	75.0	100.0	100.0	100.0	100.0	100.0
Aerodynamic enhancements	4.0	35.0	65.0	65.0	65.0	100.0	100.0	100.0
Low-heat-rejection (adiabatic) engines	10.0	0.0	0.0	0.0	20.0	50.0	100.0	100.0
Turbo-compounding	5.0	0.0	20.0	20.0	20.0	100.0	100.0	100.0
Intercooled engines	5.0	50.0	52.5	52.5	52.5	100.0	100.0	100.0
High temperature insulation (e.g. use of ceramics)	2.0	0.0	5.0	5.0	5.0	50.0	100.0	100.0
Tyres	4.0	0.0	50.0	75.0	100.0	100.0	100.0	100.0

a. Unless otherwise stated all penetration rate estimates are based on BTCE assumptions.

b. Brosthaus (1991).

Source BTCE estimates.

TABLE 10.4 TECHNOLOGY ENHANCEMENTS FOR DIESEL POWERED ARTICULATED TRUCKS

Technology option	Fuel efficiency improvement (per cent/vehicle)	Technology penetration base rate (per cent)	Assumed technology penetration rate[a]: basecase (per cent)			Assumed technology penetration rate[a]: accelerated technology scenario (per cent)		
		1995	2005	2010	2015	2005	2010	2015
Supercharging/turbocharging	10.0[b]	85.0	95.0	95.0	95.0	100.0	100.0	100.0
High pressure fuel injection	10.0[b]	0.0	20.0	20.0	20.0	100.0	100.0	100.0
Electronic fuel injection control	10.0[b]	50.0	75.0	100.0	100.0	100.0	100.0	100.0
Aerodynamic enhancements	7.0	55.0	75.0	75.0	75.0	100.0	100.0	100.0
Low-heat-rejection (adiabatic) engines	10.0	0.0	0.0	0.0	20.0	50.0	100.0	100.0
Turbo-compounding	5.0	0.0	20.0	20.0	20.0	100.0	100.0	100.0
Intercooled engines	5.0	50.0	52.5	52.5	52.5	100.0	100.0	100.0
High temperature insulation (e.g. use of ceramics)	2.0	0.0	5.0	5.0	5.0	50.0	100.0	100.0
Tyres	4.0	0.0	50.0	75.0	100.0	100.0	100.0	100.0

a. Unless otherwise stated all penetration rate estimates are based on BTCE assumptions.

b. Brosthaus (1991).

Source BTCE estimates.

and articulated trucks were derived on the basis of these assumptions. The enhanced fuel intensities formed the basis for the BTCE's projections of total road freight transport emissions to 2015 assuming accelerated implementation of advanced technologies.

Basecase fuel intensity assumptions

The basecase fuel intensity assumptions used in this Report differ slightly from the basecase fuel intensity assumptions in BTCE (1995c, pp. 38–39). In general, in this Report the average fuel intensity of new freight vehicles is assumed to decline slightly more, on the basis of the assumed technology penetration rates in tables 10.1 to 10.4.

LCVs

For LCVs, the average vehicle load is assumed to increase by about 17 per cent over the period 1995 to 2015, as outlined in BTCE (1995c, pp. 38–39). The additional fuel penalty of higher loads is offset against the fuel efficiency gains from the assumed technological advances outlined in tables 10.1 and 10.2. The net result is an improvement in new vehicle fuel efficiency of approximately 5.6 per cent between 1995 and 2005, 11.6 per cent between 2005 and 2010, and 1.5 per cent between 2010 and 2015. This represents a fuel efficiency improvement for LCVs of approximately 19.6 per cent over the period 1995 to 2015.

Rigid trucks

As in BTCE (1995c, pp. 38–39) the average load carried by rigid trucks is assumed to increase by 1 per cent per annum to 2015. The assumed increase in vehicle loads is offset against the assumed technological advances outlined in table 10.3. As a result the fuel efficiency of new rigid trucks improves by approximately 8.3 per cent between 1995 and 2005, 5.5 per cent between 2005 and 2010, and no further improvement in vehicle fuel efficiency between 2010 and 2015. On average, the overall fuel efficiency of rigid trucks improves by 10.3 per cent over the period 1995 to 2015.

Articulated trucks

The average load carried by articulated trucks is assumed to grow by 0.7 per cent per annum, similar to growth during the 1980s (BTCE 1995c, pp. 37–39). Based on the assumptions outlined in table 10.4, the improvement in new vehicle fuel efficiency for articulated trucks is approximately 10.3 per cent between 1995 and 2005, 6.5 per cent between 2005 and 2010, and 3.0 per cent between 2010 and 2015. Fuel efficiencies of articulated trucks improve on average by approximately 21.0 per cent over the period 1995 to 2015; broadly consistent with the assumptions made in BTCE (1995c, p. 216).

Accelerated technology implementation fuel efficiency assumptions

LCVs

Based on the fuel efficiency improvements and penetration rates outlined in tables 10.1 to 10.4, the average fuel efficiency gain for new LCVs from accelerated uptake of technology enhancements is approximately 27.7 per cent between 1995 and 2005, and 2.8 per cent between 2005 and 2010. There are no further fuel efficiency gains to be exploited between 2010 and 2015, as the accelerated technology implementation practically exhausts all of the currently proven technologies by about 2005. The assumptions result in average fuel efficiency improvement of 31.3 per cent for new LCVs over the period 1995 to 2015.

Rigid trucks

Based on the fuel efficiency improvements and penetration rates outlined in tables 10.1 to 10.4, the average fuel efficiency gain for new rigid trucks from accelerated uptake of technology enhancements is approximately 37 per cent between 1995 and 2005, and 6 per cent between 2005 and 2010. All fuel efficiency gains from currently applicable technology enhancements will have been exploited by 2010. The assumptions result in an improved average fuel efficiency for rigid trucks of 45.2 per cent over the period 1995 to 2015.

Articulated trucks

Based on the fuel efficiency improvements and penetration rates outlined in tables 10.1 to 10.4, the average fuel efficiency gain for new articulated trucks from accelerated uptake of technology enhancements is approximately 43 per cent between 1995 and 2005, and 6 per cent between 2005 and 2010. All fuel efficiency gains from potentially applicable technology enhancements are assumed to have been exploited by 2010. The assumptions result in average fuel efficiency improvements of 51.6 per cent over the period 1995 to 2015 for new articulated trucks.

RESULTS

Tables 10.5 and 10.6 show total CO_2 equivalent emission levels for each year 1995 to 2015 under the basecase and the accelerated technology implementation scenarios.

Figure 10.2 shows the level of CO_2 equivalent emissions under the basecase and accelerated technology implementation scenarios for all types of commercial vehicles. It is clear that CO_2 equivalent emissions from the road freight sector continue to increase, even under what the BTCE considers is a most optimistic accelerated technology implementation scenario. By 2015, CO_2 equivalent emissions would be reduced by approximately 20 per cent compared with the basecase (table 10.7).

TABLE 10.5 PROJECTED BASECASE CO_2 EQUIVALENT EMISSIONS FROM ROAD FREIGHT VEHICLES, 1995 TO 2015

(gigagrams)

Year	*LCVs*	*Rigid trucks*	*Articulated trucks*	*All commercial vehicles*
1995	9 346	5 200	6 761	21 308
1996	9 996	5 305	6 936	22 238
1997	10 653	5 408	7 122	23 183
1998	11 297	5 508	7 294	24 099
1999	11 886	5 606	7 490	24 982
2000	12 328	5 703	7 693	25 723
2001	13 072	5 798	7 900	26 770
2002	13 848	5 893	8 113	27 853
2003	14 634	5 986	8 327	28 948
2004	15 431	6 079	8 555	30 064
2005	16 264	6 170	8 784	31 218
2006	17 080	6 256	9 033	32 369
2007	17 819	6 338	9 288	33 444
2008	18 508	6 416	9 560	34 483
2009	19 189	6 488	9 838	35 515
2010	19 851	6 555	10 148	36 554
2011	20 526	6 623	10 453	37 601
2012	21 222	6 692	10 772	38 686
2013	22 030	6 762	11 111	39 902
2014	22 879	6 828	11 475	41 182
2015	23 809	6 893	11 805	42 507

Source BTCE estimates.

TABLE 10.6 PROJECTED CO_2 EQUIVALENT EMISSIONS FROM ROAD FREIGHT VEHICLES UNDER THE ACCELERATED TECHNOLOGY IMPLEMENTATION SCENARIO, 1995 TO 2015

(thousand tonnes)

Year	*LCVs*	*Rigid trucks*	*Articulated trucks*	*All commercial vehicles*
1995	9 346	5 200	6 761	21 308
1996	9 963	5 284	6 900	22 146
1997	10 552	5 346	7 017	22 916
1998	11 094	5 390	7 098	23 581
1999	11 550	5 417	7 176	24 143
2000	11 833	5 429	7 241	24 504
2001	12 375	5 429	7 294	25 098
2002	12 911	5 418	7 337	25 665
2003	13 422	5 396	7 367	26 185
2004	13 907	5 365	7 395	26 666
2005	14 388	5 323	7 412	27 123
2006	14 885	5 284	7 456	27 626
2007	15 353	5 251	7 518	28 122
2008	15 817	5 221	7 604	28 642
2009	16 313	5 195	7 705	29 214
2010	16 836	5 174	7 839	29 848
2011	17 383	5 161	7 985	30 528
2012	17 963	5 156	8 155	31 275
2013	18 648	5 161	8 352	32 160
2014	19 383	5 168	8 578	33 130
2015	20 201	5 182	8 792	34 174

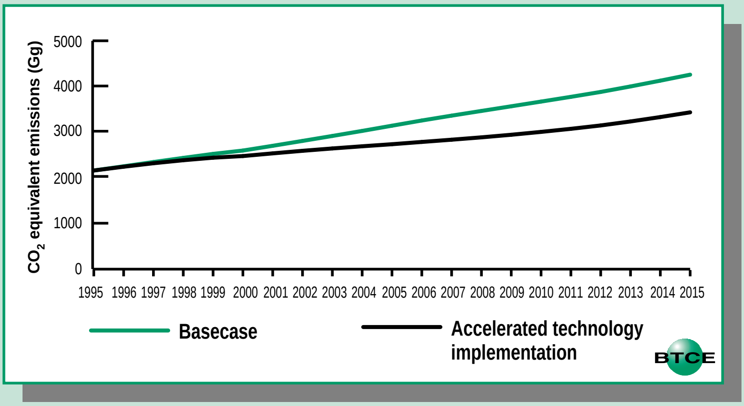
Source BTCE estimates.

Most of the savings in emissions come from the shift of freight currently handled by rigid trucks, to articulated trucks. It is primarily the assumed increase in the urban freight task of LCVs that causes total emissions of LCVs to increase, and this outweighs the reduction in emissions from increased fuel efficiency of new LCVs.

Costs of accelerating the implementation of new technology

The net costs of accelerated introduction of new technology are equal to the sum of benefits forgone in consumption and production, the cost of additional resources used, and the costs of external effects where social marginal cost diverges from private marginal cost. Examples of external costs include health and safety costs.

FIGURE 10.2 FUEL SAVING TECHNOLOGY FOR ROAD FREIGHT VEHICLES: PROJECTED CO_2 EQUIVALENT EMISSIONS FROM COMMERCIAL VEHICLES



Source BTCE estimates.

The main costs in consumption are the additional cost of new vehicle technology to vehicle buyers. The cost to domestic vehicle producers/assemblers equals the reduction in their economic profits. Reduced fuel use represents a resource cost saving.

Most of the costs are made up of the additional technology costs and the fuel cost savings. Useful discussions on the measurement of costs in markets where distortions occur are found in Just, Hueth and Schmitz (1982, pp. 177–199) and Sugden and Williams (1978, pp. 134–147).

Tables 10.8 and 10.9 give the assumed additional per vehicle cost of technology enhancements for commercial vehicles. For many of the enhancements for diesel powered vehicles, the cost is assumed to be the same for different vehicle types. This assumption was required because there are few estimates available about the cost of enhancements for different vehicle types.

The different technology options will operate over different lifetimes. Tyres, for example, have to be replaced on average just over once a year for passenger cars but more frequently for freight vehicles because of the higher kilometre usage. In estimating the additional costs of technology over the lifetime of the vehicle, each technology had to be weighted by how often it would have to be replaced within the lifetime

TABLE 10.7 PERCENTAGE REDUCTION IN CO_2 EQUIVALENT EMISSIONS FROM ROAD FREIGHT VEHICLES UNDER THE ACCELERATED TECHNOLOGY IMPLEMENTATION SCENARIO, 1995 TO 2015

(per cent)

Year	*LCVs*	*Rigid trucks*	*Articulated trucks*	*All commercial vehicles*
1995	0.00	0.00	0.00	0.00
1996	0.33	0.40	0.53	0.41
1997	0.95	1.13	1.47	1.15
1998	1.80	2.14	2.69	2.15
1999	2.83	3.38	4.20	3.36
2000	4.01	4.80	5.87	4.74
2001	5.33	6.37	7.67	6.25
2002	6.76	8.07	9.57	7.86
2003	8.28	9.86	11.53	9.54
2004	9.88	11.75	13.56	11.30
2005	11.53	13.72	15.62	13.12
2006	12.85	15.53	17.45	14.65
2007	13.84	17.16	19.05	15.91
2008	14.54	18.62	20.46	16.94
2009	14.98	19.92	21.68	17.74
2010	15.19	21.07	22.75	18.34
2011	15.31	22.07	23.61	18.81
2012	15.36	22.95	24.30	19.16
2013	15.35	23.68	24.83	19.40
2014	15.28	24.31	25.24	19.55
2015	15.15	24.83	25.53	19.60

Source BTCE estimates.

of the vehicle. The additional vehicle technology costs were calculated using the weighted lifetime cost of each technology.

Applying the cost estimates in tables 10.8 and 10.9 resulted in the estimated cost of a new rigid truck increasing by about 45 per cent over current average prices, whereas the cost of new LCVs and articulated trucks increased by between 10 and 15 per cent. In the initial cost calculation, this caused a large discrepancy between the net costs of implementing new technology for different vehicle types.

TABLE 10.8 ADDITIONAL PER VEHICLE COST OF TECHNOLOGY ENHANCEMENTS: DIESEL POWERED VEHICLES

(1995–96 $/vehicle)

Technology option	*LCVs*	*Rigid trucks*	*Articulated trucks*
Supercharging/turbocharging	1 100	1 100	1 100
High pressure fuel injection	2 100	2 100	2 100
Electronic fuel injection control	600	600	600
Aerodynamic enhancements	2 100	7 100	10 600
Low-heat-rejection (adiabatic) engines	11 000	11 000	11 000
Turbo-compounding	8 500	8 500	8 500
Intercooled engines	1 600	1 600	1 600
High temperature insulation (e.g. use of ceramics)	8 000	8 000	8 000
Tyres	400	800	1 500

Note The costs contained in the table are the ‘on-road’ costs of each type of technology. The costs were converted to Australian dollars using the 1994–95 annual average retail rate of exchange between the US dollar and the Australian dollar (US$ 0.7405 per $A). The costs were scaled up by the average tariff rate as at 1 July 1992 (15 per cent for road freight vehicles, which is legislated to fall to 5 per cent at 1 July 1996) and the sales tax rate (21 per cent) on commercial vehicles and parts, to derive the cost to Australian consumers.

Source BTCE estimates based on DeCicco et al. 1993.

A large difference in the relative costs of different vehicles could result in a shift out of rigid trucks by transport operators. This in turn would mean the assumptions made about the number of new rigid trucks entering the fleet would be invalid. For simplicity analysis of costs was based on an assumed increase in rigid truck prices of around 10 to 15 per cent over current market prices, equal in percentage terms to the increase in average vehicle prices for LCVs and articulated trucks. In contrast to the assumptions used here, it is possible that the cost of rigid truck technology will be large relative to the market price. This would significantly affect the number of new rigid trucks purchased compared to the present assumptions about future growth in rigid truck numbers, but quantitative results were not estimated for such a scenario.

Tables 10.10 and 10.11 show the cumulative costs, in 1995–96 $, of accelerated technology implementation scenarios in 2000 and 2015. The loss in consumer surplus represents the additional cost to vehicle buyers of technology enhanced vehicles less any fuel cost savings attributable

TABLE 10.9 ADDITIONAL PER VEHICLE COST OF TECHNOLOGY ENHANCEMENTS: PETROL POWERED VEHICLES

(1995–96 $/vehicle)

Technology option	*LCVs*
Aerodynamic improvement: drag reduction	169
4-speed automatic	40
Torque converter lock-up	74
Electronic transmission control	127
Accessory improvements	61
Roller cams	32
Low friction piston/rings	169
10W-30 oil	0
Tyre improvements	42
4-valve engines	222
Multi-point fuel injection (additional gain over CFI)	141
Central fuel injection	50
Front wheel drive	317
5-speed automatic (additional gain over 4-speed automatic)	317
Variable valve timing	169
Electric power steering	200
CVT (additional gain over 5-speed automatic)	211
Weight reduction (increase)	450

Note The costs contained in the table are the 'on-road' costs of each type of technology. The costs were converted to Australian dollars using the 1994–95 annual average retail rate of exchange between the US dollar and the Australian dollar (US$ 0.7405 per $A). The costs were scaled up by the average tariff rate as at 1 July 1992 (15 per cent for road freight vehicles, which is legislated to fall to 5 per cent at 1 July 1996) and the sales tax rate (21 per cent) on commercial vehicles and parts, to derive the cost to Australian consumers.

Source BTCE estimates based on DeCicco et al. 1993.

to those vehicles. Domestic producer costs are assumed to be negligible as most commercial vehicle technology is manufactured overseas and imported into Australia (Federal Chamber of Automotive Industries pers. comm. 1994). The increased cost of new technology is fully captured in the increased cost to consumers. Government costs represent the reduction in fuel excise receipts as a result of the reduced sale of automotive fuels. The reduction in government fuel excise receipts is not a resource cost, but is a transfer payment.

The accelerated uptake of vehicle technology enhancements will have a beneficial impact on health and safety as a result of reduced fossil fuel

TABLE 10.10 TOTAL COST OF ACCELERATED TECHNOLOGY IMPLEMENTATION FOR ROAD FREIGHT VEHICLES BY VEHICLE TYPE, 2000

(1995–96 $ million)

	LCVs	*Rigid trucks*	*Articulated trucks*	*All commercial vehicles*
Consumers	–24.62	74.45	–55.27	–5.44
Producers	na	na	na	na
Government	55.7	59.8	93.7	209.2
Externalities	0.02	–0.05	–0.13	–0.16
Total	31.1	134.2	38.4	203.7

na Not available

Note Negative numbers represent a net benefit. Costs are expressed in present values (1995–96 $) using a discount rate of 10 per cent.

Source BTCE estimates.

TABLE 10.11 TOTAL COST OF ACCELERATED TECHNOLOGY IMPLEMENTATION FOR ROAD FREIGHT VEHICLES BY VEHICLE TYPE, 2015

(1995–96 $ million)

	LCVs	*Rigid trucks*	*Articulated trucks*	*All commercial vehicles*
Consumers	–1 506.65	–277.57	–1 366.97	–3 151.29
Producers	na	na	na	na
Government	869.2	659.0	1 030.0	2 558.1
Externalities	0.35	–0.33	–0.93	–0.91
Total	–637.2	381.1	–338.0	–594.1

na Not available

Note Negative numbers represent a net benefit. Costs are expressed in present values (1995–96 $) using a discount rate of 10 per cent.

Source BTCE estimates.

consumption. The technology options considered will be likely to have different effects on different gas types. For diesel powered vehicles, some technology enhancements may increase noxious emissions. Because of data limitations, non-CO_2 emissions have been assumed to change at the same rate as CO_2 emissions. The reduction in total fuel consumption is therefore assumed to result in beneficial health effects.

TABLE 10.12 TOTAL ANNUAL NET SOCIAL COSTS OF ACCELERATED TECHNOLOGY IMPLEMENTATION FOR ROAD FREIGHT VEHICLES, 1996 TO 2015

($1995–96 million)

	LCVs	*Rigid trucks*	*Articulated trucks*	*All commercial vehicles*
1996	5.5	14.5	7.9	27.9
1997	8.1	24.1	10.6	42.8
1998	8.2	29.6	9.3	47.2
1999	6.3	32.8	7.3	46.5
2000	3.0	33.1	3.3	39.3
2001	–1.6	33.2	–1.4	30.2
2002	–7.1	31.4	–6.1	18.2
2003	–13.2	29.5	–10.7	5.5
2004	–19.6	27.6	–14.6	–6.6
2005	–26.3	25.4	–18.7	–19.6
2006	–40.7	20.4	–23.8	–44.1
2007	–51.4	17.9	–27.5	–61.0
2008	–59.1	15.9	–29.4	–72.7
2009	–64.6	14.7	–30.7	–80.6
2010	–68.1	14.0	–29.7	–83.9
2011	–66.7	9.5	–34.1	–91.3
2012	–65.0	5.6	–36.4	–95.8
2013	–63.4	2.8	–37.4	–98.0
2014	–61.6	0.5	–37.6	–98.7
2015	–59.8	–1.4	–38.2	–99.4

Note Negative numbers represent a net benefit. Costs are expressed in present values (1995–96 $) using a discount rate of 10 per cent.

Source BTCE estimates.

Because the number of new vehicles in the fleet is assumed to remain the same, the change in total congestion costs is negligible. The value of externality benefits presented in tables 10.10 and 10.11 is based on estimates of the approximate unit costs of environmental damage by airborne pollutants **(appendix table X.1)**. The externality benefits are calculated using the average urban and non-urban cost of 0.11 cents per kilometre. Emissions of particulates are not presently included in TRUCKMOD and so any reduction is not included in the measure of the external benefits, although they are potentially significant in urban areas.

The value of the externality benefits is less than 1 per cent of total private costs.

All costs reported have been attributed to the year in which they are incurred. Fuel cost savings are counted in the year in which they occur, and are not attributed back to the year in which the vehicle was purchased.

Table 10.12 shows the total annual cost to society of the full accelerated technology implementation scenario. Given the individual technology costs outlined in tables 10.8 and 10.9, the accelerated implementation of technology enhancements would generate a net welfare gain to society by the year 2004. That is, the analysis suggests that accelerated technology implementation is at least in part a ‘no regrets’ option.

Figure 10.1 and table 10.13 show the marginal cost of six intermediate, and full implementation of accelerated technology scenarios in 2000, 2005, 2010 and 2015. Comparison of the graphs shows that the cumulative reduction in emissions is greater by 2015 than in 2000. Marginal costs per unit reduction of CO_2 equivalent emissions are lower over the longer time period.

Sensitivity testing

The cost of technology enhancements and the rate of penetration are highly uncertain. The results of sensitivity analysis undertaken on the cost of new technology suggests that if technology costs were 50 per cent above the costs given in tables 10.8 and 10.9, then the accelerated implementation of technology would impose a net cost to society (BTCE 1996e, p. 38).

It is important to note the BTCE’s analysis relies on source cost data (DeCicco et al. 1993) that appear to be the price in 1995 US$ of new technologies to be introduced progressively between 1990 and 2030. Because the cost data appear to report the real price of new technology to be produced at some future date, there are significant research and development costs and plant set-up costs where present values would be much larger if they had to be brought forward. That is, to accelerate the development of new technology and incorporate it into new vehicles would increase costs significantly above the estimated levels included in this Report. The BTCE could not find any information to estimate how the technology costs would increase if the introduction of new technology were brought forward. The BTCE undertook the analysis using the best available information and has included some sensitivity results that show the point at which new technology is not a ‘no regrets’ policy.

TABLE 10.13 FUEL SAVING TECHNOLOGY FOR ROAD FREIGHT VEHICLES: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1) Intensity[b]	*(2)* Cumulative reduction: CO_2 equivalent (thousand tonnes)	*(3)* Change in cumulative reduction: CO_2 equivalent (thousand tonnes)	*(4)* Social cost of cumulative reduction ($ million)	*(5)* Change in social cost ($ million)	*(6)* Average social cost[c] ($ per tonne)	*(7)* Marginal social cost[d] ($ per tonne)
1996 to 2000						
1	900	900	–30	–30	–33	–33
3	1 600	700	–75	–45	–47	–64
4	1 800	200	–73	2	–41	10
5	2 200	400	–23	50	–10	125
6	2 500	300	50	73	20	243
FI	2 900	400	204	154	70	385
1996 to 2005						
1	5 300	5 300	–140	–140	–26	–26
3	9 200	3 900	–380	–240	–41	–62
4	10 500	1 300	–410	–30	–39	–23
5	12 800	2 300	–320	90	–25	39
6	14 300	1 500	–150	170	–10	113
FI	17 100	2 800	230	380	13	136
1996 to 2010						
1	13 500	13 500	–290	–290	–21	–21
3	24 400	10 900	–840	–550	–34	–50
4	27 900	3 500	–950	–110	–34	–31
5	34 200	6 300	–840	110	–25	17
6	38 200	4 000	–620	220	–16	55
FI	46 000	7 800	–110	510	–2	65
1996 to 2015						
1	22 100	22 100	–390	–390	–18	–18
3	42 500	20 400	–1230	–840	–29	–41
4	49 300	6 800	–1420	–190	–29	–28
5	61 600	12 300	–1330	90	–22	7
6	69 000	7 400	–1100	230	–16	31
FI	84 600	15 600	–590	510	–7	33

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. The intensity measure for new technology refers to staggered implementation of fuel-saving technology. Technology alternatives are implemented in order of least cost per unit reduction in emissions, based on cost estimates in De Cicco et al. (1993). *Intensity level 1* includes electronic fuel injection for diesel vehicles and improved oil and

4-speed automatic for gasoline vehicles. *Intensity level 3* includes level 1 technology and high pressure fuel injection and supercharging for diesel vehicles, and fuel injection, torque converter lockup and 4-valve engines for gasoline vehicles. *Intensity level 4* includes level 3 technology and intercooled engines for diesel vehicles, and variable valve timing and aerodynamic improvements for gasoline vehicles. *Intensity level 5* includes level 3 technology and low-heat-rejection engines for diesel vehicles, and low friction engines and accessory improvements for gasoline vehicles. *Intensity level 6* includes turbocompounding for diesel vehicles, and 5-speed automatic for gasoline vehicles. The remaining technology options implemented under the full accelerated technology implementation scenario (FI) are improved tyres, aerodynamic enhancements and high temperature insulation for diesel vehicles, and continuously variable transmission, front wheel drive and tyre improvements for gasoline powered vehicles.

c. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates based on DeCicco 1993.

To calculate the marginal costs of accelerated technology implementation each individual technology enhancement was introduced into the fleet in stages according to the per unit cost of the expected fuel efficiency improvement. The total cost and cumulative emissions benefit from each individual technology enhancement were used to calculate the marginal cost.

A discount rate of 10 per cent was used to discount future costs back to constant 1995–96 $ levels. Using a 5 per cent discount rate increases the cumulative net benefits to 2015, because the annual fuel cost savings are greatest towards 2015, when a greater number of more fuel-efficient vehicles have entered the fleet. Equally, a discount rate of 15 per cent penalises future fuel cost savings more heavily, and this reduces the net benefits of the accelerated technology.

EQUITY ISSUES

Under accelerated technology implementation, most of the costs of the scheme would fall upon purchasers of new vehicles, who would incur the additional capital costs. Additional capital costs would be offset to some extent by lower fuel costs over the working life of the vehicle.

Motor vehicle manufacturers would face increased research and development costs and production costs. These increased producer costs would eventually be recovered through increased revenue from higher vehicle prices. Overall, motor vehicle manufacturers would probably experience some fall in total profits. Most commercial vehicles are manufactured overseas, but are assembled in Australia, and therefore there will be some impact on local inductry.

Any increase in vehicle costs would be passed on by vehicle operators, through higher road freight cartage rates. As most goods sold for final consumption require transport to the final point of sale, higher road freight cartage rates could result in small increases in the shelf price of most goods within the economy.

Government revenue from new vehicle sales would be expected to fall initially, due to reduced demand for new vehicles following a price increase. Government fuel excise revenue from road freight vehicles is also likely to shrink as a result of reduced demand for freight services.

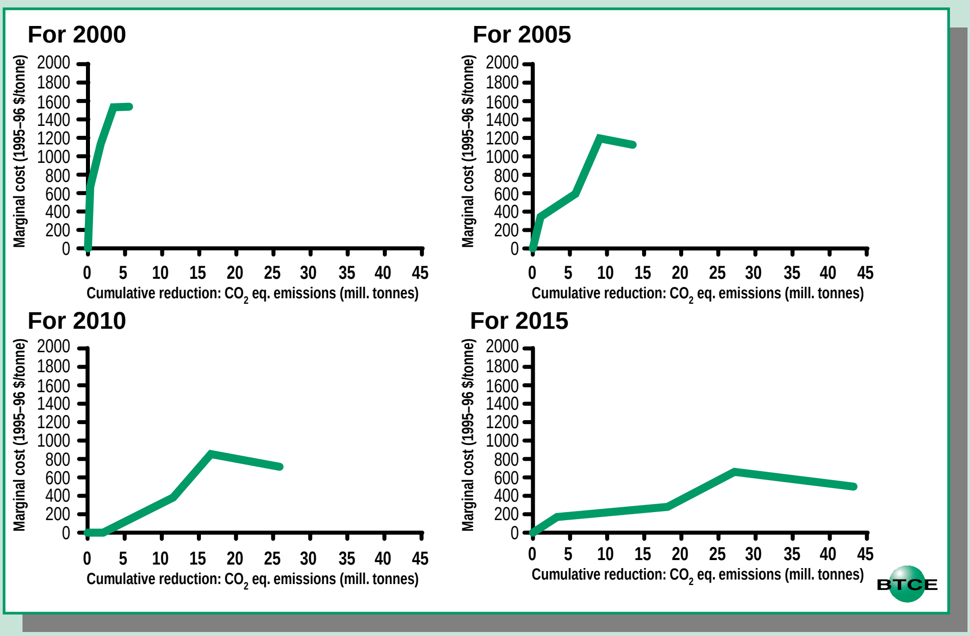
In summary, if the capital cost of the new technology option outweighs the present value of future fuel savings, government revenue will fall, prices of consumer goods will generally increase, the road freight transport sector will shrink, and sales of new road freight vehicles will decline.

...AT A GLANCE

Greenhouse emissions could be ameliorated by accelerated retirement (scrapping) from service of the least fuel-efficient road freight vehicles. A maximum cumulative reduction in CO_2 equivalent emissions of 43 million tonnes could be achieved by the year 2015 at a marginal cost in that year of $500 per tonne.

- It was assumed for the purposes of analysis that vehicles that reach a specific age are scrapped.
- Developed specifically by the BTCE for its Greenhouse Study, the TRUCKMOD model was used to assess the effect on the average fuel efficiency of Australia's fleet of commercial vehicles of changes to the age distribution of the fleet.

FIGURE 11.1 ACCELERATED ROAD FREIGHT VEHICLE SCRAPPING: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 11 ACCELERATED SCRAPPING OF OLDER ROAD FREIGHT VEHICLES

Accelerated scrapping, or earlier retirement, of more polluting road freight vehicles can reduce growth in total greenhouse emissions.

A number of countries have policies that encourage the early scrapping of passenger vehicles. State based programs in California, Illinios and Delaware encourage scrapping of old vehicles through 'cash for clunkers' type schemes, where the government offers cash to owners of high emitting vehicles (Alberini, Harrington & McConnell 1994; Alberini, Edelstein et al. 1994).

The measure assessed here extends the concept of accelerated scrapping to trucks and light commercial vehicles (LCVs).

Accelerated vehicle retirement schemes can be implemented in two main forms, either as a mandatory (or compulsory) retirement scheme, where a vehicle is refused registration if it fails to meet specified requirements, or as a voluntary retirement scheme, where financial inducements are offered to owners in exchange for scrapping their vehicles. Financial compensation for vehicle owners may or may not accompany a mandatory retirement scheme. The costs of a mandatory retirement scheme where there is no compensation are borne in the first instance by vehicle owners, while taxpayers would bear the cost of voluntary scrapping schemes or mandatory retirement schemes with compensation to vehicle owners.

A voluntary vehicle retirement scheme can target the more polluting vehicles by making a financial offer only to the most polluting vehicles. A voluntary retirement scheme requires a policy decision on prices to be offered to vehicle owners. Vehicle offer prices must be sufficiently high to attract owners to retire their vehicle. The size of any voluntary retirement scheme would be constrained by the budget allocation.

Mandatory retirement schemes, as well as targeted voluntary retirement schemes, require specification of criteria for vehicles to be scrapped. Criteria could include emission rates, vehicle age (in years or kilometres travelled), and/or vehicle fuel efficiency.

Total greenhouse emissions are a product both of vehicle emission rates and of total vehicle usage. From a greenhouse perspective it would be more sensible to use emission rates and/or fuel efficiency as the specified criteria. A scheme based on emission rates would require regular checking of all vehicles, preferably during on-road travel rather than just at test centres. Because emission rates depend to a large extent on fuel efficiency (which directly determines CO_2 emissions), fuel efficiency too could be used as a criterion, although monitoring would again prove to be a major problem.

There is little information available on the fuel efficiency of the road freight vehicle fleet, and the BTCE was unable to find any studies of voluntary road freight vehicle retirement schemes. For these reasons it was decided to assess the cost and effectiveness of an age based mandatory retirement scheme for road freight vehicles.

Implementation of an age based mandatory retirements scheme was based on the mandatory retirement of all vehicles within the following age groups:

1. All freight vehicles over 30 years of age.
2. All freight vehicles over 20 years of age.
3. All freight vehicles over 18 years of age.
4. All freight vehicles over 15 years of age.
5. All freight vehicles over 12 years of age.

The choice of age groups is arbitrary; selected to keep the analysis simple. Analysis based on a different set of age groups would not affect the substantive results.

A mandatory retirement scheme based on vehicle age would be less efficient than a scheme based on emission rates, because vehicle age may in practice bear little relationship to vehicle usage and deterioration. Such a scheme would not reward owners who initially purchased more fuel-efficient vehicles, and it would generate a disincentive to maintain vehicles as they approached the mandatory scrapping age.

METHODOLOGY

Analysis of the accelerated scrapping of freight vehicles assumed implementation from 1996 continuing to 2015.

Implementation of an accelerated scrapping policy would result immediately in a shortfall of road freight vehicles necessary to handle the total road freight task. An immediate result would be a reallocation of vehicles among tasks, a reduction in the underlying scrapping rate for vehicles not affected by the policy, and an increase in the number of new vehicles purchased. It could also lead to an increase in the intensity of vehicle use in terms of average kilometres travelled and an increase in average loads. It was not possible, however, to estimate the magnitude of these effects.

For the purposes of the analysis, the total road freight task was assumed to remain unchanged after imposition of a policy to accelerate scrapping of road freight vehicles. Average kilometres travelled and average loads of vehicles remaining in the fleet were also assumed to remain unchanged. The number of additional new vehicles entering the fleet and the number of vehicles of younger vintages that, if not for the policy, would otherwise have been scrapped was assumed to be just sufficient to transport the unchanged total road freight task. In TRUCKMOD, new vehicles are assumed to carry the same average load as the vehicle they replace, but the average VKT of new vehicles is greater than that for older vehicles. To undertake the road freight task the number of additional new vehicles entering the fleet will therefore be significantly less than the number of vehicles scrapped.

It was necessary to make these simplifying assumptions to keep the analysis tractable. But one consequence is that the assumption of no change in the total road freight task will tend to understate the actual reduction in the road freight task that would occur as a result of an accelerated scrapping policy. The simulation results using TRUCKMOD will therefore tend to understate the actual reduction in emissions.

In the first year of implementation of an accelerated scrapping policy there will be a large number of old freight vehicles scrapped. In each subsequent year for which the policy is maintained, only those vehicles that pass the threshold age will be scrapped, so that fewer vehicles will be scrapped in subsequent years. As a consequence, costs will tend to be highest in 1996 and will fall substantially thereafter.

Estimating emission reductions and costs

The cost of an accelerated scrapping measure is equal to the additional resource cost of undertaking the original transport task plus the value of any additional benefits forgone.

Cost is measured here as the sum of:

- the present value of future services that the scrapped vehicles would otherwise have been used to provide, less costs associated with maintaining and running the vehicle; and
- net changes in government tax revenue. Increased sales of new vehicles will increase sales tax receipts, a reduced stock of vehicles will reduce state government vehicle registration receipts, and a fall in demand for automotive fuels will reduce fuel excise receipts.

The number of vehicles to be scrapped is determined directly by the scrapping policy. The displaced freight task (that is the freight task that would have been handled by the vehicles scrapped) is the product of average VKT and average vehicle loads of those vehicles scrapped, and the number of vehicles scrapped. The additional number of new vehicles necessary to undertake the displaced freight task is derived using average VKT and average vehicle loads of new vehicles.

Only a fraction of the displaced freight task will be handled by new vehicles. Forced vehicle scrapping will result in some vehicles remaining in the fleet that otherwise would have been scrapped, and an increase in the number of new vehicles. New vehicles are assumed to take up only 10 per cent of the displaced freight task for scrapping of 30-year and older vehicles. The share of the displaced task undertaken by new vehicles increases as the intensity of the vehicle scrapping policy increases.

Changes in total fuel consumption were calculated as the difference between total fuel consumption before and after implementation of the scrapping policy. Total fuel use is equal to the product of average vehicle fuel efficiency, average VKT, and the number of vehicles.

Estimates of average costs of scrapping vehicles of different ages are based on vehicle costs derived from *Glass's Guide* (1995 and earlier issues). *Glass's Guides* give retail prices obtained by a franchise dealer for a truck of a given age in 'guide condition'. For the purpose of this analysis, 'guide condition' generally means that the vehicle is in roadworthy condition and is carrying approximately six months registration. This is important for the purposes of deriving the net value of future services provided by a used vehicle, which is the principal cost of vehicle scrapping.

Glass's Guide gives used vehicle prices only for vehicles up to 10 years of age. The policy measure considered includes scrapping of vehicles well over 10 years of age. To estimate prices of vehicles over 10 years of age the BTCE constructed a depreciation function for each of LCVs, rigid trucks and articulated trucks. The real depreciation function was estimated on data for the first 10 years of a vehicle's life, and extrapolated to derive the average price of vehicles up to 30 years of age.

The estimated real depreciation functions are given by the following relationships.

LCVs:

$$V_t = V_0 . \exp(-0.117t) \tag{11.1}$$

Rigid trucks:

$$V_t = V_0 . \exp(-0.567 - 0.090t) \tag{11.2}$$

Articulated trucks:

$$V_t = V_0 . \exp(-0.139t) \tag{11.3}$$

where V_t is the real price of a vehicle at age t, V_0 is the real price of a new vehicle, and exp is the base of the natural logarithm.

Average market prices of used vehicles of a particular age are derived by applying the appropriate depreciation function to historical records of real prices of new vehicles.

The economic surplus enjoyed by a road freight vehicle owner is equal to the financial return generated by operating the vehicle less total maintenance and operating costs. The market price of a road freight vehicle only gives the net value of the services provided by vehicles at the 'margin'. That is, the value of the services provided by the vehicle are just equal to the value of services in the vehicle's next best alternative use. For used vehicles which are not traded, the value of the services provided must be at least as great as the value of the vehicle in its next best alternative use. So the economic surplus generated by a vehicle used in a particular activity will be at least equal to the market price. The market price therefore is an underestimate of the total economic surplus generated by each (except for the 'marginal' vehicle) of the used vehicles to be scrapped. The cost estimates presented below therefore underestimate the cost to vehicle owners of the accelerated scrapping policy.

The market price used to estimate the costs of the scrapping policy is the average market price for vehicles within a particular age group.

The change in tax revenue is equal to the change in new vehicle sales tax receipts and fuel excise receipts. Additional new vehicle sales tax revenue is estimated by taking the average real retail price of a new vehicle and the sales tax rate and multiplying by the number of additional new vehicles purchased. The change in total fuel excise revenue is equal to the change in total fuel used multiplied by the fuel excise rate. Changes in tax revenues represent transfer payments, not resource costs.

The implementation of an accelerated scrapping policy would result in an increased demand for used vehicles that are not due to be scrapped. This would result in more of these used vehicles remaining on the road than would otherwise have occurred. The additional registration revenue (also a transfer payment) from these vehicles must be included in total social cost.

RESULTS

The number of trucks scrapped would differ according to the severity of the accelerated scrapping policy (table 11.1). In 1996, if all vehicles over the age of 30 years were mandatorily scrapped, this would result in the scrapping of 15 300 LCVs, 11 600 rigid trucks and 1300 articulated trucks.

If the mandatory scrapping policy remained in operation the number of vehicles scrapped in subsequent years would be significantly less than in 1996, the year of implementation.

The reduction in CO_2 equivalent emissions is smallest in 1996, and this reduction increases steadily each year as more new vehicles enter the fleet and greater numbers of older and less fuel-efficient vehicles are forced out of the fleet. The greatest reduction in CO_2 equivalent emissions will come from scrapping of LCVs, as there are a greater number of older LCVs remaining on the road. The smallest reduction in CO_2 equivalent emissions is achieved from scrapping of rigid trucks.

TABLE 11.1 CUMULATIVE NUMBER OF ROAD FREIGHT VEHICLES SCRAPPED UNDER VARIOUS ACCELERATED SCRAPPING SCENARIOS, 1996 TO 2015

(thousand vehicles)

Year	*Age >30 yrs*	*Age >20 yrs*	*Age >18 yrs*	*Age >15 yrs*	*Age >12 yrs*
1996	28.2	176.0	230.5	301.8	380.6
1997	30.1	192.1	240.4	313.5	386.8
1998	32.3	204.6	251.4	316.0	397.4
1999	34.4	218.1	259.5	317.3	404.4
2000	36.5	227.6	270.9	328.5	406.0
2001	38.3	239.3	283.9	342.3	406.6
2002	40.0	255.1	293.1	346.7	417.8
2003	41.7	267.0	302.2	357.0	425.6
2004	43.3	274.2	320.9	368.7	413.9
2005	44.6	290.2	333.6	366.9	403.4
2006	45.9	307.3	331.0	358.6	405.3
2007	47.4	308.7	326.5	355.3	418.5
2008	48.3	305.5	330.0	360.1	426.6
2009	48.5	310.3	336.2	364.9	462.4
2010	48.5	319.6	336.6	373.3	488.9
2011	48.6	324.6	339.6	399.7	512.8
2012	48.6	327.9	360.8	434.4	544.1
2013	48.4	346.6	380.9	464.1	573.8
2014	48.7	364.2	409.1	492.2	677.7
2015	49.5	390.6	441.4	552.6	695.0

Source BTCE estimates.

Tables 11.2 and 11.3 show the impact that forced scrapping of freight vehicles would have in reducing emission levels of greenhouse gases. In the short term (up to the year 2000) it would be necessary to scrap virtually all commercial vehicles older than about 20 years to be certain of reducing emissions from road freight vehicles by more than 1 per cent per annum. If all vehicles over 12 years of age were scrapped, the maximum attainable emission reduction would peak in the year 2015 at about 9 per cent compared to basecase emission levels.

Mandatory accelerated scrapping of freight vehicles therefore offers the potential of moderate reductions in greenhouse gas emissions. However, the marginal costs of these reductions using age-based scrapping of trucks are rather high.

TABLE 11.2 TOTAL CO_2 EQUIVALENT EMISSIONS FROM ROAD FREIGHT VEHICLES UNDER VARIOUS ACCELERATED SCRAPPING SCENARIOS, 1995 TO 2015

(thousand tonnes)

Year	*Basecase*	*Age >30 yrs*	*Age >20 yrs*	*Age >18 yrs*	*Age >15 yrs*	*Age >12 yrs*
1995	21 308	21 308	21 308	21 308	21 308	21 308
1996	22 238	22 211	22 097	21 995	21 697	21 329
1997	23 183	23 138	22 936	22 838	22 558	22 188
1998	24 099	24 036	23 753	23 651	23 404	22 954
1999	24 982	24 903	24 536	24 440	24 236	23 764
2000	25 723	25 627	25 180	25 100	24 894	24 448
2001	26 770	26 656	26 133	26 066	25 817	25 388
2002	27 853	27 721	27 128	27 077	26 817	26 339
2003	28 948	28 799	28 135	28 083	27 837	27 341
2004	30 064	29 900	29 176	29 103	28 870	28 400
2005	31 218	31 039	30 250	30 182	29 929	29 463
2006	32 369	32 177	31 318	31 273	31 005	30 425
2007	33 444	33 242	32 326	32 290	32 025	31 309
2008	34 483	34 272	33 316	33 274	32 988	32 086
2009	35 515	35 297	34 310	34 271	33 911	32 645
2010	36 554	36 331	35 315	35 289	34 842	33 492
2011	37 601	37 376	36 340	36 308	35 760	34 387
2012	38 686	38 459	37 405	37 342	36 643	35 343
2013	39 902	39 672	38 586	38 501	37 761	36 436
2014	41 182	40 947	39 828	39 711	38 961	37 593
2015	42 507	42 272	41 112	40 952	40 210	38 795

Source BTCE estimates.

Tables 11.4 and 11.5 show the cumulative costs in constant 1995–96 $ of accelerated scrapping of older commercial vehicles in 2000 and 2015. Most of the cost of accelerated scrapping is borne initially by vehicle owners and users of the services provided by them. Loss of revenue from lower levels of fuel excise is not compensated by increased sales taxes, so that government receipts are reduced.

An accelerated vehicle scrapping policy would ideally remove more highly polluting vehicles from the vehicle fleet. This would produce health benefits for the community. Any overall reduction in vehicle numbers is also likely to reduce congestion costs, but as commercial vehicles make up only a small proportion of the vehicle fleet it is likely

TABLE 11.3 PERCENTAGE REDUCTION IN CO_2 EQUIVALENT EMISSIONS FROM ROAD FREIGHT VEHICLES UNDER VARIOUS ACCELERATED SCRAPPING SCENARIOS, 1996 TO 2015

(per cent)

Year	*Age >30 yrs*	*Age >20 yrs*	*Age >18 yrs*	*Age >15 yrs*	*Age >12 yrs*
1996	0.12	0.63	1.09	2.43	4.09
1997	0.19	1.06	1.49	2.70	4.29
1998	0.26	1.43	1.86	2.88	4.75
1999	0.32	1.79	2.17	2.99	4.88
2000	0.37	2.11	2.42	3.23	4.96
2001	0.43	2.38	2.63	3.56	5.16
2002	0.47	2.60	2.79	3.72	5.44
2003	0.51	2.81	2.99	3.84	5.55
2004	0.55	2.95	3.20	3.97	5.54
2005	0.57	3.10	3.32	4.13	5.62
2006	0.59	3.25	3.39	4.21	6.01
2007	0.61	3.34	3.45	4.24	6.38
2008	0.61	3.38	3.51	4.34	6.95
2009	0.61	3.39	3.50	4.52	8.08
2010	0.61	3.39	3.46	4.68	8.38
2011	0.60	3.36	3.44	4.90	8.55
2012	0.59	3.31	3.47	5.28	8.64
2013	0.58	3.30	3.51	5.36	8.69
2014	0.57	3.29	3.57	5.39	8.71
2015	0.55	3.28	3.66	5.40	8.73

Source BTCE estimates.

that any change in congestion costs will be small. It has been assumed that the change in congestion costs is negligible.

The health and safety benefits associated with accelerated scrapping of old vehicles are measured as the environmental damage caused by airborne pollutants **(appendix table X.1)**. Externality benefits were calculated using average urban and non-urban driving cycles. The value of the externality benefits presented in tables 11.4 and 11.5 are less than 1 per cent of the total costs.

Table 11.6 shows that the costs of accelerated scrapping increase quickly as the mandatory scrapping age is lowered. The present value of costs of

TABLE 11.4 DISCOUNTED TOTAL COST OF ACCELERATED ROAD FREIGHT VEHICLE SCRAPPING BY VEHICLE AGE, IN 2000

(1995–96 $ million)

	Age >30 yrs	Age >20 yrs	Age >18 yrs	Age >15 yrs	Age >12 yrs
Consumers	30.0	283.4	415.3	675.0	1 169.9
Producers	na	na	na	na	na
Government	7.7	43.4	49.0	64.1	96.5
Externalities	–0.5	–2.8	–3.1	–4.2	–6.4
Total	37.1	323.9	461.2	734.9	1 260.0

na Not available because the producer surplus of domestic new truck suppliers is assumed to remain unchanged.

Source BTCE estimates.

TABLE 11.5 DISCOUNTED TOTAL COST OF ACCELERATED ROAD FREIGHT VEHICLE SCRAPPING BY VEHICLE AGE, IN 2015

(1995–96 $ million)

	Age >30 yrs	Age >20 yrs	Age >18 yrs	Age >15 yrs	Age >12 yrs
Consumers	6.0	81.7	130.0	246.1	460.6
Producers	na	na	na	na	na
Government	4.7	28.0	30.8	44.7	71.1
Externalities	–0.1	–0.5	–0.7	–1.1	–1.7
Total	10.6	109.2	160.1	289.7	529.9

na Not available as the producer surplus of domestic new truck suppliers is assumed to remain unchanged.

Source BTCE estimates.

accelerated scrapping falls with time. This fall is reflected in figure 11.1, which illustrates the steep increase in costs incurred in the short run for every additional tonne reduction in CO_2 equivalent emissions. Marginal abatement costs fall to about half their year 2000 level by the year 2015. Marginal abatement costs also rise less quickly as the rate of scrapping is increased.

Sensitivity testing

Sensitivity analysis indicates that accelerated scrapping of road freight vehicles is a net cost to society irrespective of the discount rate used.

TABLE 11.6 TOTAL COST OF ACCELERATED ROAD FREIGHT VEHICLE SCRAPPING, 1996 TO 2015

(1995–96 $ million)

Year	*Age >30 yrs*	*Age >20 yrs*	*Age >18 yrs*	*Age >15 yrs*	*Age >12 yrs*
1996	46.0	391.5	649.6	1 143.7	1 857.6
1997	43.5	384.1	562.1	1 014.2	1 689.4
1998	41.4	365.0	527.1	899.1	1 583.0
1999	39.3	346.8	490.6	790.4	1 430.8
2000	37.1	323.9	461.2	734.9	1 260.0
2001	34.9	304.4	424.8	699.9	1 132.5
2002	32.7	289.8	380.8	630.0	1 055.5
2003	30.6	269.4	355.3	574.6	957.1
2004	28.5	245.1	347.9	525.3	806.6
2005	26.4	231.8	319.9	466.1	709.9
2006	24.4	222.2	280.0	408.9	661.7
2007	22.6	200.6	251.8	363.7	662.6
2008	20.8	178.1	233.5	331.7	636.7
2009	18.9	162.8	213.1	308.0	694.6
2010	17.1	151.4	188.4	295.5	670.3
2011	15.6	138.2	171.2	301.2	641.0
2012	14.1	124.6	166.3	315.0	603.2
2013	12.7	117.6	162.7	307.1	569.1
2014	11.5	112.0	159.7	290.6	601.1
2015	10.5	109.2	160.1	289.7	529.9

Note Costs are expressed in present values (1995–96 $) using a discount rate of 10 per cent.

Source BTCE estimates.

The results show that using a higher discount rate reduces the present value of future costs, thus reducing the cumulative present value cost of the policy, and vice versa for a lower discount rate (BTCE 1996e).

EQUITY ISSUES

An accelerated scrapping policy, requiring uncompensated mandatory retirement of vehicles on the basis of age, would place the cost largely on existing owners of vehicles. Forced scrapping of vehicles would affect owner operators, many of whom operate on low margins.

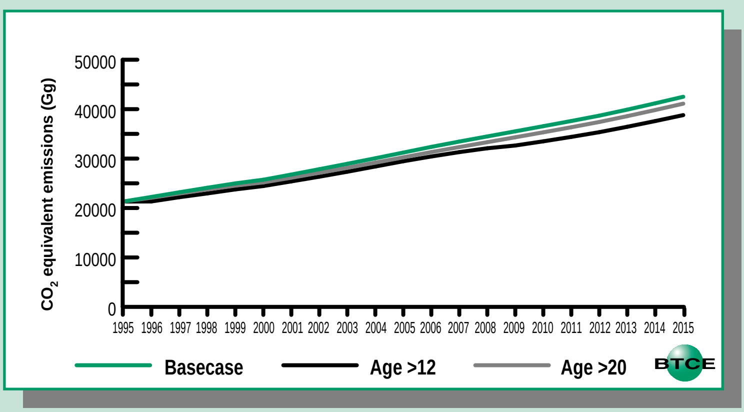
Other effects of introducing an accelerated scrapping policy include:

- in the short term, an increase in the value of vehicles that are not scrapped immediately, representing a transfer of wealth to remaining used vehicle owners;
- possibly increased prices of new vehicles, an increased cost for new vehicle purchasers;
- an increase in the price of freight transport services, representing a transfer from consumers to suppliers of freight transport services. This would tend to increase the cost of goods for which transport is a necessary input before final sale.

These effects are largely a transfer of wealth between different agents in the economy.

To the extent that governments sought to increase taxation receipts or to reduce expenditure to make up for the shortfall caused by loss of fuel excise, some groups of taxpayers would also suffer a loss in income.

FIGURE 11.2 TOTAL EMISSIONS PROFILE UNDER ALTERNATIVE ROAD FREIGHT VEHICLE SCRAPPING POLICIES



Source BTCE estimates.

TABLE 11.7 ACCELERATED SCRAPPING OF ROAD FREIGHT VEHICLES: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1) Age of vehicles scrapped	(2) Cumulative reduction: CO_2 equivalent	(3) Change in cumulative reduction: CO_2 equivalent	(4) Social cost of cumulative reduction	(5) Change in social cost	(6) Average social cost[b]	(7) Marginal social cost[c]
(years)	(thousand tonnes)	(thousand tonnes)	($ million)	($ million)	($ per tonne)	($ per tonne)
1996 to 2000						
Age >30	300	300	210	210	700	700
Age >20	1 700	1 400	1 810	1 600	1 060	1 140
Age >15	3 400	1 700	4 580	2 770	1 350	1 630
Age >12	5 500	2 100	7 820	3 240	1 420	1 540
1996 to 2005						
Age >30	1 000	1 000	360	360	360	360
Age >20	5 800	4 800	3 200	2 840	550	590
Age >15	9 000	3 200	7 500	4 300	830	1 340
Age >12	13 500	4 500	12 500	5 000	930	1 110
1996 to 2010						
Age >30	2 100	2 100	460	460	220	220
Age >20	11 500	9 400	4 070	3 610	350	380
Age >15	16 600	5 100	9 190	5 120	550	1 000
Age >12	25 900	9 300	15 810	6 620	610	710
1996 to 2015						
Age >30	3 200	3 200	530	530	170	170
Age >20	18 100	14 900	4 670	4 140	260	280
Age >15	27 200	9 100	10 690	6 020	390	660
Age >12	43 200	16 000	18 750	8 060	430	500

a. All costs are cumulated from 1996 to each of the years shown expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. Average costs (rounded to the nearest dollar) are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

c. Marginal costs (rounded to the nearest dollar) are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

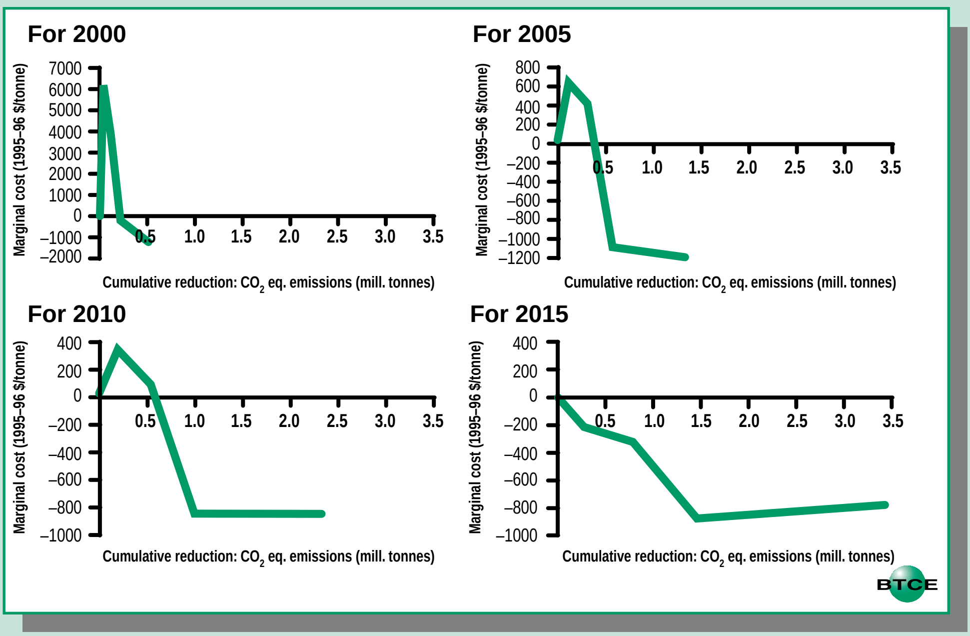
Source BTCE estimates based on DeCicco 1993.

...AT A GLANCE

Shifting about 40 per cent of intercapital road freight to rail could produce net social benefits by 2015. However, reductions in greenhouse gas emissions would be only about 0.5 per cent of basecase emissions from road freight vehicles. Although this measure can be regarded as one of 'no regrets', it is limited in scope for reducing emissions.

- Interstate freight is the main area where enticing freight from road to rail appears feasible, provided that rail could improve its standard of service through shorter transit times.
- A significant investment in track infrastructure—$3.4 billion over the next 14 years—would potentially induce a transfer of up to 40 per cent of intercapital road freight to rail. If this were to occur, there would be net social benefits because reduced transit times and lower rail operating costs (resulting mainly from lower maintenance costs) would outweigh the capital costs of track upgrading on all the corridors studied by 2015.
- But the Australian road transport industry has a well earned reputation for its capacity to develop attractive logistical solutions for its customers and can be expected to respond aggressively to a greater competitive threat from rail. A shift of 40 per cent of road freight to rail may thus be difficult to achieve in practice.
- No assessment has been made of whether public investment could be directed more profitably to areas other than rail upgrades, with reductions in greenhouse gas emissions achieved more effectively using other measures.

FIGURE 12.1 SHIFTING INTERCAPITAL FREIGHT FROM ROAD TO RAIL: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Note y-scales do not match.

Source BTCE estimates.

CHAPTER 12 SHIFTING INTERCAPITAL FREIGHT FROM ROAD TO RAIL

The intercapital freight market is the main area where road freight could be shifted profitably to rail. At present, road offers a higher quality service in terms of time and reliability for door-to-door delivery, but at a somewhat higher door-to-door price than rail for many consignments. The increasing premium placed on quality of service has resulted in rail steadily losing market share over the past quarter of a century (figure 12.2).

A key element in the achievement of high standards of service is the development by the service provider of a culture that focuses on meeting the logistical needs of the customer. The road transport industry has, to date, been more successful than the rail industry in this regard.

Infrastructure also has a role to play. There are currently deficiencies in the intercapital rail network. Average speeds on the network range from 50 to 80 kilometres an hour, reflecting the configuration and condition of the track. There is limited track duplication and a shortage of adequate passing loops, which reduces the capacity of the network and affects rail freight reliability. For example, where there are access conflicts, passenger services are routinely given precedence over freight services. The condition of the track also imposes high maintenance costs on operators.

It was assumed that upgrading of track is implemented sequentially on the four intercapital rail links as follows:

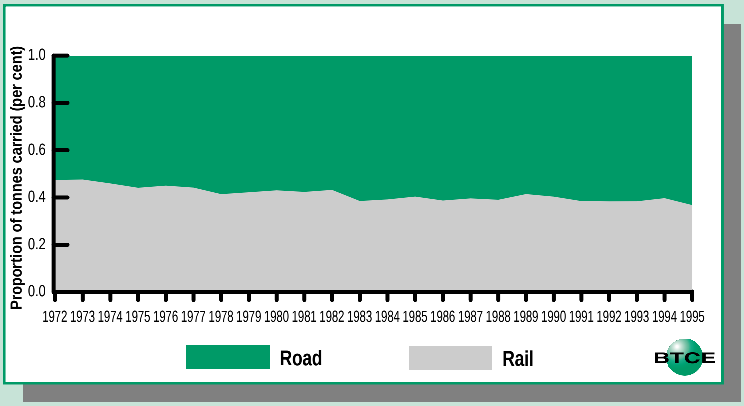
(1) Sydney–Melbourne

(2) Sydney–Brisbane

(3) Melbourne–Adelaide

(4) Adelaide–Perth

FIGURE 12.2 MARKET SHARE OF INTERCAPITAL FREIGHT BY ROAD AND RAIL, 1972–1995



Source BTCE estimates.

Sequential upgrading of links in this way involves not only improving qualitatively the links between pairs of cities, but also the generation of a network effect. As the number of interconnected cities grows, so does the utility to each city from the upgraded network. Part of the analysis of the emission reductions from the scenarios therefore involved specification of the increasing network benefits that would arise as the upgraded sections were brought together.

In defining the upgrading scenario, it was assumed that the rail infrastructure investment could be carried out in two separate stages (BTCE 1995a). The stage 1 and stage 2 investments are assumed to be implemented during the years 1996–2000 and 2006–2010, respectively. Stage 2 is thus complementary to stage 1. Stage 1 includes realignment of track to increase train speeds; new 60-kilogram rail and new concrete sleepers to permit carriage of heavier trains and freight; control systems, passing loops and sidings to permit increased frequency of use by trains; and improvements in clearances, urban access and terminals. Stage 2 includes further 60-kilogram rail, further raising of clearances to allow double stacking of containers (4.8 metres), stronger bridges, lower track gradients, passing loops and sidings, control systems, terminals, and grade separation to reduce hold-ups from trains labouring up a grade.

TABLE 12.1 PRIMARY EFFECTS OF ASSUMED STAGE 1 AND STAGE 2 INTERCAPITAL RAIL INVESTMENTS ON KEY SERVICE ATTRIBUTES, 1996 TO 2010

Service attribute	*Stage 1 1996–2000*	*Stage 2 2006–2010*
Reduction in transit time (hours)		
Sydney–Melbourne	15 to 13	13 to 10
Sydney–Brisbane	19 to 13	13 to 10
Melbourne–Adelaide	14 to 12	12 to 9
Adelaide–Perth	45 to 33	33 to 26
Increase in average speed (kilometres/hour)		
Sydney–Melbourne	70 to 80	80 to 100
Sydney–Brisbane	50 to 80	80 to 100
Melbourne–Adelaide	65 to 80	80 to 100
Adelaide–Perth	66 to 80	80 to 100
Increase in reliability (average delay in minutes)		
Sydney–Melbourne	95 to 48	48 to 19
Sydney–Brisbane	168 to 49	49 to 20
Melbourne–Adelaide	58 to 40	40 to 16
Adelaide–Perth	199 to 132	132 to 53

Source BTCE 1995a, p. 84.

It is expected that the upgrading of rail infrastructure systems would improve rail transit times, average speeds, and reliability, as well as significantly reducing track maintenance costs. The main expected effects of these investments by corridor are summarised in table 12.1.

METHODOLOGY

Rail operating costs are sensitive to traffic volumes. To predict the future effect of a freight shifting measure, not only do tonnages shifted need to be specified, but the basecase tonnages also need to be estimated.

Basecase rail tonnages were estimated by developing an econometric model. The model considered the amount of rail non-bulk freight tonnages as being influenced by the Australian real gross non-farm product and capacity utilisation, with dummy variables to represent the introduction of superfreighters from 1988 and the closure of the Adelaide–Melbourne corridor in 1995 (to allow for upgrading the link to standard gauge). The basecase tonnages were compared with tonnages expected to be carried after infrastructure investments had been made. Reductions in road freight tonnages were taken to be equal to the expected increase in rail tonnages. The rationale behind this simplifying assumption was that the measure was aimed to encourage the shift of freight from road to rail, and not to increase the growth of the intercapital freight market, although growth in the total market might still occur. Details of the model specification and assumptions used are presented in **appendix XII**.

Estimation of greenhouse gas emissions requires estimates of fuel efficiency and changes in tonne-kilometres carried by road and rail. It was assumed that the fuel efficiencies of both road and rail after the implementation of the measure did not change as a result of upgrading rail infrastructure, although improvement in gradients would also improve fuel efficiencies on some sections of the track. Details of the fuel consumption model are given in appendix XII.

Costing estimates included infrastructure investment expenditures, rail and road accident expenditures, rail and road total operating expenditures, road damage expenditures, and customer service quality. Taxes and charges paid by rail and road operators are treated as transfer payments. These payments include truck taxes and charges and fuel excise for both road and rail.

Infrastructure investment expenditures represent the major cost components associated with the policy measure. The infrastructure investment proposal is based on the results of analysis for the NTPT (BTCE 1995a, p. 51). The costs and timing of rail infrastructure investment are summarised in table 12.2.

TABLE 12.2 RAIL INFRASTRUCTURE INVESTMENT EXPENDITURES BY CORRIDOR, 1996 TO 2010

(1995–96 $ million)

Stage of investment	*Sydney–Melbourne*	*Sydney–Brisbane*	*Melbourne–Adelaide*	*Adelaide–Perth*	*Total*
Stage 1: 1996–2000	480	555	190	38	1 263
Stage 2: 2006–2010	540	445	405	765	2 155
Total	1 020	1 000	595	803	3 418

Source BTCE 1995a, p. 51.

As a result of the increased use of rail services, rail accidents can be expected to rise slightly. The annual social cost of rail accidents was assumed to be $94.5 million (BTCE 1995b, p. 1). Because the cost refers to both passenger and freight activities, it is worth noting that there is a possibility of overestimating the cost attributable to freight, and caution should be exercised when using these values. Total rail freight tonnages were estimated to be 212.1 million tonnes (BTCE 1995c, p. 49), resulting in an estimated unit cost of rail accidents of 45.9 cents per tonne. The total tonnages used in the derivation of the unit cost are based on total bulk and non-bulk tonnages carried in 1995 by the government railways.

The total operating expenditure of rail is expected to decline due to improvements in operating efficiencies. The reduction was derived by taking the difference between total operating expenditures before and after the rail infrastructure investment stages are completed. The average total operating cost in before and after investment periods (table 12.3) were obtained using the RAILCOST model (BTCE 1995d). Note that although the Adelaide–Perth line is a long-distance route suited to rail, its operating costs are not significantly lower. This is due to the low traffic volumes on the route.

Assuming that there would be insignificant changes in the composition of the existing Australian truck fleet, increased use of rail would reduce the total number of trucks being used. A reduction in total truck operating expenditures results from the reduction in truck net tonne-kilometres. The amount of savings involved is derived by multiplying the total reduction in truck tonne-kilometres by truck unit operating costs. Truck unit operating cost is estimated to be 6.9 cents per net tonne-kilometre in 1995–96 (DOT 1995a, p. 42). This cost is derived using the operating characteristics of six-axle articulated trucks. An average annual

TABLE 12.3 AVERAGE TOTAL OPERATING COST FOR RAIL, 1996 TO 2010

(1995–96 cents per net tonne-kilometre)

Corridor	*Investment 1996–2000*	*Investment 2005–2010*
Sydney–Melbourne	4.25 to 3.06	3.06 to 2.33
Sydney–Brisbane	3.89 to 2.94	2.94 to 2.27
Melbourne–Adelaide	3.28 to 2.66	2.66 to 2.18
Adelaide–Perth	3.30 to 2.97	2.97 to 2.47

Source BTCE estimates.

linehaul was assumed to be 200 000 kilometres and the unit operating cost was estimated at $1.52 per kilometre, based on a 22 tonne average load. It is also assumed that the unit operating cost will drop by 15 per cent over the period 1996 and 2015, reflecting partially the increased use of B-doubles. The same unit operating cost has been used to derive estimates of savings for all other corridors.

It is likely that there would be a reduction in road damage and associated costs due to the decline in freight carried by road. Reductions in road damage expenditure were estimated by multiplying the reduction in truck net tonne-kilometres by road damage costs per net tonne-kilometre. A road damage cost of 0.85 cents per net tonne-kilometre (BTCE 1993a, p. 135) was used. The damage cost is based on an estimate for six-axle articulated trucks on the Sydney–Melbourne corridor. In the absence of other information, this value was used to derive estimates of total road damage expenditure for all other corridors.

Trucks were involved in about 10 per cent of road accidents involving hospitalisation in 1994 and about 20 per cent of fatal road crashes (FORS, pers. comm. 22 May 1995). It was assumed that truck-related accidents would be reduced as more freight is carried by rail. The reduction in road accident expenditure is derived by multiplying a cost for accidents involving articulated trucks of 0.2 cents per net tonne-kilometre (BTCE 1995e, p. 22) by the reduction in truck net tonne-kilometres.

Improvements in rail service quality provide an increase in benefits to consumers in terms of faster transit times and increased reliability. Estimates of increased customer service benefits are based on the assumption that differences in the quality of service are reflected as differences in charges for road and rail freight. As an approximation, prices for road and rail freight have been derived using the respective unit operating costs. While road pricing is assumed to follow the structure of its unit operating costs, it is assumed that rail pricing would move closer to that of road following the completion of the stage 1 and stage 2 investments.

Fuel excise and taxes and charges paid by both road and rail operators are treated as transfer payments. Rail fuel excise payments are related directly to the amount of fuel consumption. Increased rail tonnages imply an increase in the amount of fuel use. The amount of excise revenue gained as a consequence of shifting freight from road to rail is estimated using excise charges of 39.2 cents per litre (Australian Institute of Petroleum Ltd, pers. comm. 20 February 1996).

The smaller number of trucks used would result in reduced government revenue collection from federal and state taxes and charges. Reductions in government revenue collection are derived by multiplying the reduction in truck-kilometres by a unit government taxes and charges rate of 28.67 cents per kilometre (DOT 1995a, p. 27). This unit charge refers to the average level of taxes and charges imposed on articulated trucks with six axles.

RESULTS

The shifting of freight from road to rail was found to be only of minor significance in its potential to reduce greenhouse gas emissions. The maximum fuel and emissions savings are only about 0.5 per cent of total emissions from the road freight sector if all four rail corridors are upgraded, as shown in the following calculation:

> Intercapital road freight is 12 per cent of trucking (i.e. 28 000 million tonne-kilometres). But long-distance trucks are the most fuel efficient. Thus intercapital road freight accounts for 3.5 per cent of total truck fuel use.
>
> Maximum shift to rail is 37.5 per cent of intercapital trucking (i.e. 10.5 million tonne-kilometres).
>
> Rail uses 49 per cent less fuel than road per tonne.
>
> But rail is only 83 per cent as emissions-efficient as road.
>
> Also road distances are shorter than rail distances (about 94 per cent of rail's).
>
> Thus the fuel and emissions savings are about 0.5 per cent of total projected truck fuel use in 2015 (i.e. $3.5 \times 0.375 \times 0.49 \times 0.83 \times 0.94$).

About a third of truck tonne-kilometres carried in Australia occurs within cities, where there is little or no opportunity for transfer to rail. Moreover, much of the non-urban rail task is too diffuse to lend itself to transport by rail. This leaves only the 12 per cent of trucking which serves the intercapital market as a potential target for a switch to rail. But intercapital road freight is carried by long-distance trucks that are very fuel efficient compared with shorter-distance trucks and light commercial vehicles, so that only about 3.5 per cent of total trucking fuel use could be affected. Estimates presented by the NTPT (BTCE 1995a, p. 51) assume that only 37.5 per cent of intercapital road freight could be shifted to rail, with fuel use gains of less than half of the truck fuel use involved (as rail freight uses about half of the fuel per tonne-kilometre of road and generally travels longer distances).

Total net costs become negative as more corridors are completed and the full network benefits are realised (table 12.4). Shippers of goods from Brisbane to Melbourne can use the network after a Sydney–Brisbane link upgrading is added to the Sydney–Melbourne link. These users are in addition to the users gained on the Sydney–Brisbane and Sydney–Melbourne direct links. Adding Melbourne–Adelaide and Adelaide–Perth upgradings multiplies the number of such additional 'network' users that are gained. Appendix XII discusses these network effects.

Shifting intercapital freight from road to rail is estimated to produce net social benefits (negative costs) as well as reducing greenhouse gas emissions, and these benefits increase as the network is progressively upgraded. The resulting marginal costs are thus negative and declining as more links are upgraded (figure 12.1, table 12.5).

Shifting intercapital freight from road to rail is a 'no regrets' measure—where the social costs of reducing greenhouse gas emissions are outweighed by the expected social benefits. However, this is not to say that there are not other investments that might yield a higher return to the community.

TABLE 12.4 SHIFTING INTERCAPITAL FREIGHT FROM ROAD TO RAIL: CUMULATIVE TOTAL NET COSTS, 1996 TO 2015

(1995–96 $ million)

Corridor sequentially upgraded	*1996–2000*	*1996–2005*	*1996–2010*	*1996–2015*
Sydney–Melbourne	255	68	65	–59
Sydney–Brisbane	551	151	97	–223
Melbourne–Adelaide	530	–134	–290	–811
Adelaide–Perth	172	–1 040	–1 418	–2 342

Note Negative values represent a net benefit (i.e. a 'no regrets' situation). Costs are expressed in present values (1995–96 $) using a 10 per cent discount rate.

Source BTCE estimates.

TABLE 12.5 SHIFTING INTERCAPITAL FREIGHT FROM ROAD TO RAIL: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1) Corridor[b]	*(2)* Cumulative reduction: CO_2 equivalent *(million tonnes)*	*(3)* Change in cumulative reduction: CO_2 equivalent *(million tonnes)*	*(4)* Social cost of cumulative reduction *($ million)*	*(5)* Change in social cost *($ million)*	*(6)* Average social cost[c] *($ per tonne)*	*(7)* Marginal social cost[d] *($ per tonne)*
1996 to 2000						
Sydney–Melbourne	0.041	0.041	255	255	6 220	6 220
Sydney–Brisbane	0.118	0.077	551	296	4 669	3 844
Melbourne–Adelaide	0.219	0.101	530	–21	2 420	–208
Adelaide–Perth	0.512	0.293	172	–358	336	–1 222
1996 to 2005						
Sydney–Melbourne	0.107	0.107	68	68	636	636
Sydney–Brisbane	0.305	0.198	151	83	495	419
Melbourne–Adelaide	0.568	0.263	–134	–285	–236	–1 084
Adelaide–Perth	1.328	0.760	–1 040	–906	–783	–1 192
1996 to 2010						
Sydney–Melbourne	0.187	0.187	65	65	348	348
Sydney–Brisbane	0.533	0.346	97	32	182	92
Melbourne–Adelaide	0.991	0.458	–290	–387	–293	–845
Adelaide–Perth	2.323	1.332	–1 418	–1 128	–610	–847
1996 to 2015						
Sydney–Melbourne	0.276	0.276	–59	–59	–214	–214
Sydney–Brisbane	0.787	0.511	–223	–164	–283	–321
Melbourne–Adelaide	1.459	0.672	–811	–588	–556	–875
Adelaide–Perth	3.430	1.971	–2 342	–1 531	–683	–777

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. Upgrading of tracks is implemented sequentially on the four intercapital rail links.

c. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates.

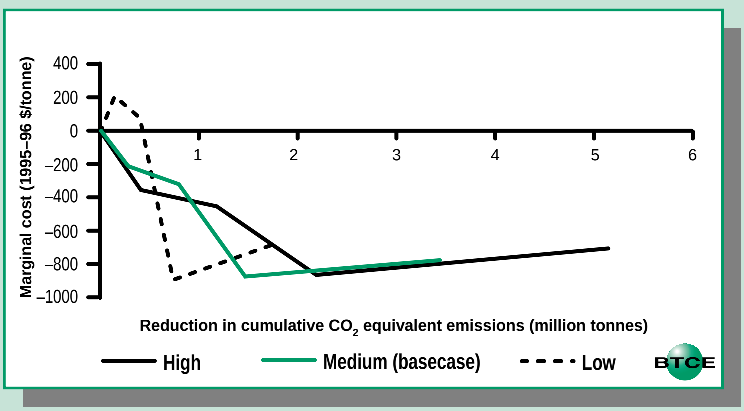
Sensitivity testing

Reduced transit times would improve the attractiveness of rail to intercapital freight operators, but this may not, of itself, be enough to induce as large a transfer of freight as assumed in this Report. The Australian road transport industry has a well earned reputation for its capacity to develop attractive logistical solutions for its customers and can be expected to respond aggressively to a greater competitive threat from rail.

The sensitivity of the results with regard to the assumed amount of freight shifted was tested by assuming 50 per cent more, and 50 per cent less freight transferred from road. Figure 12.3 and table 12.6 show the effect on the cost components to 2015 of varying the assumptions about freight transfer. The main effect of assuming more (or less) freight transfer from road to rail is that there is more (or less) emissions benefit. The marginal cost curves are shifted roughly to the right (or left).

Sensitivity testing with discount rates of 5 and 15 per cent did not materially alter the conclusions. Marginal costs remained primarily negative for the year 2015 irrespective of the rate used.

FIGURE 12.3 SENSITIVITY TESTING: MARGINAL SOCIAL COSTS OF SHIFTING INTERCAPITAL FREIGHT FROM ROAD TO RAIL, 2015



Source BTCE estimates.

TABLE 12.6 SOCIAL COSTS OF SHIFTING INTERCAPITAL FREIGHT FROM ROAD TO RAIL: SENSITIVITY TESTING, 1996 TO 2015

Corridor	*Total cost (1995–96 $ million)*	*Cumulative CO_2 equivalent emissions reduction (million tonnes)*	*Average cost (1995–96 $/tonne)*	*Marginal cost (1995–96 $/tonne)*
High scenario (50 per cent more freight shifted)[a]				
Sydney–Melbourne	–147	0.414	–355	–355
Sydney–Brisbane	–495	1.180	–419	–454
Melbourne–Adelaide	–1 368	2.189	–625	–865
Adelaide–Perth	–3 457	5.145	–672	–707
Low scenario (50 per cent less freight shifted)[b]				
Sydney–Melbourne	29	0.138	210	210
Sydney–Brisbane	48	0.393	122	75
Melbourne–Adelaide	–253	0.730	–347	–893
Adelaide–Perth	–931	1.715	–543	–688

a. High scenario refers to 50 per cent more freight than the basecase transferred from road to rail.

b. Low scenario refers to 50 per cent less freight than the basecase transferred from road to rail.

Note Negative values represent net social benefit. Costs are expressed in present values (1995–96 $) using a 10 per cent discount rate.

Source BTCE estimates.

EQUITY ISSUES

Rail freight users, and ultimately consumers of the goods transported, gain from reductions in freight rates and improvements in service quality (table 12.7). The projected growth in the total road freight task in Australia is such that employment in the road freight industry would not decline—just grow slightly more slowly. Governments (taxpayers) bear the cost of infrastructure spending, but (as of 1996) would reap most of the benefit of the reductions in operating costs through their ownership of the National Rail Corporation and the track. There would be benefits accruing directly to consumers in the form of better quality of service and lower freight rates. Externality benefits are mostly in the form of reduced accident costs.

TABLE 12.7 SHIFTING INTERCAPITAL FREIGHT FROM ROAD TO RAIL: COMPOSITION OF TOTAL NET COSTS, 1996 TO 2015

(1995–96 $ million)

	Corridor sequentially upgraded			
Sector	*Sydney–Melbourne*	*Sydney–Brisbane*	*Melbourne–Adelaide*	*Adelaide–Perth*
Consumer	–149	–333	–529	–886
Producer	–482	–1 068	–1 750	–3 201
Government	579	1 199	1 511	1 843
Externalities	–7	–21	–43	–97
Total	–59	–223	–811	–2 342

Note Negative values represent a net benefit. Costs are expressed in present values (1995–96 $) using a 10 per cent discount rate.

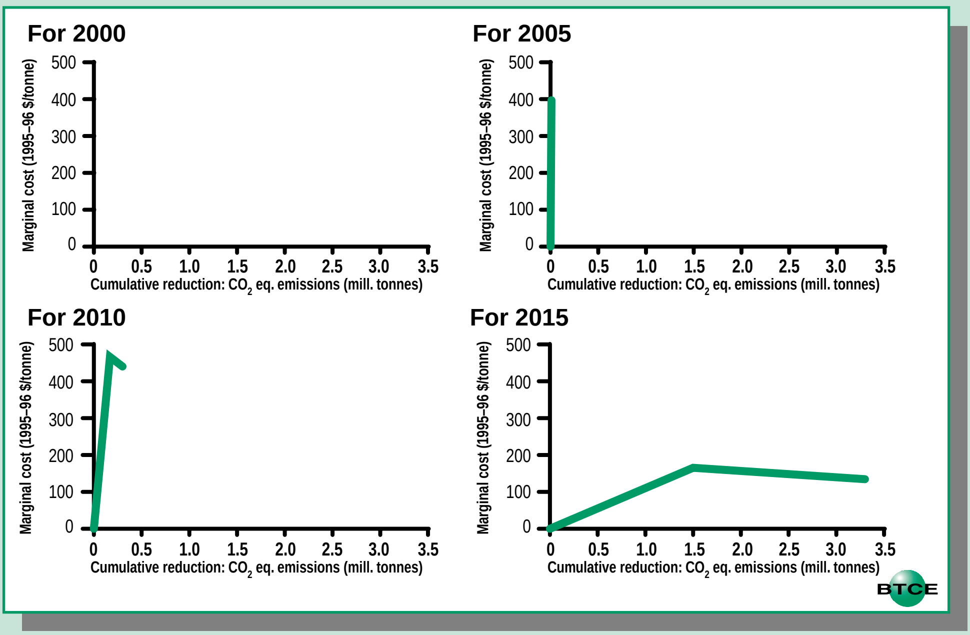
Source BTCE estimates.

...AT A GLANCE

Technological improvements to large passenger aircraft on domestic routes have the potential to reduce future growth in greenhouse gas emissions. A cumulative reduction of only 2.6 per cent in CO_2 equivalent aircraft emissions could be achieved by the year 2015. There is some limited scope for reductions at very low or negative social cost (that is, 'no regrets') although marginal social cost would be of the order of $134 per tonne of CO_2 equivalent if the maximum reduction of about 3.3 million tonnes were to be achieved.

- Greenhouse gas emissions from domestic aviation contribute about 5.5 per cent to total CO_2 equivalent emissions from the transport sector, and approximately 0.6 per cent of total Australian CO_2 equivalent emissions from all sources. By 2015, domestic aviation is expected to contribute 8.2 per cent of total CO_2 equivalent emissions from the transport sector.
- Fuel saving technological improvements could be achieved by scrapping jet aircraft after 20 years of operation, and replacing them with more fuel-efficient aircraft.
- More fuel-efficient aircraft technology could reduce annual growth in greenhouse emissions from domestic aircraft to approximately 3.4 per cent (from a projected basecase growth of 3.8 per cent).
- The social cost of reducing greenhouse emissions appears to be relatively high in the short term.

FIGURE 13.1 FUEL SAVING TECHNOLOGY FOR AIRCRAFT: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Note No technology improvement before 2005.

Source BTCE estimates.

CHAPTER 13 TECHNOLOGICAL IMPROVEMENTS FOR DOMESTIC AIRCRAFT

Domestic aviation currently contributes about 5.5 per cent of total CO_2 equivalent emissions from the Australian transport sector. Only domestic aviation was analysed in this Report, because attribution to individual countries of emissions from fuel used by aircraft on international routes remains an unresolved issue. Domestic aviation refers to military aircraft and to civil aircraft on scheduled domestic flights on trunk routes.

The four major types of aircraft emissions are carbon dioxide (CO_2), oxides of nitrogen (NO_x) other than nitrous oxide, carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs). Emissions of these gases are influenced by the stage of aircraft operation. For example, idling emits a higher proportion of hydrocarbons (HC, an element of NMVOCs), and cruising and take-offs emit mainly NO_x (Alamdari & Brewer 1994, p. 149, reproduced in BTCE 1995c, table 4.1, p. 62).

BTCE (1995c, pp. 233–234) reports domestic consumption of the two major aviation fuels: aviation turbine fuel (avtur) and aviation gasoline (avgas). Avgas is used mainly by general aviation operators and constitutes only 5 per cent of total energy used for domestic aviation. BTCE (1995c) figures for total avtur fuel consumption included fuel use by military aircraft and fuel consumption on domestic legs of international flights. Information supplied by the Department of Defence (Paul Edey, pers. comm. 18 April 1996) indicates that military aviation fuel consumption should remain fairly constant over time, so that most of the growth in domestic aviation fuel consumption will be due to increasing civil aviation activity.

The BTCE constructed AVMOD, a model of the domestic aircraft fleet and aircraft usage, in order to project total greenhouse emissions under alternative technology scenarios. AVMOD calculates future annual greenhouse emissions to 2015, based on projections of the Australian domestic aircraft fleet, by type of aircraft, average aircraft utilisation, and average aircraft fuel efficiency. Projections of the size and composition of the Australian domestic aircraft fleet are based on projected growth in passenger demand. AVMOD is described in further detail in appendix IX.

METHODOLOGY

Aviation fuel efficiency can be improved directly through measures that have an influence on the fuel efficiency of aircraft, such as improvements in aircraft technology. Average fuel efficiency can also be improved indirectly through increased load factors, scheduling efficiencies and reduced aircraft delay.

Technology options designed to improve the fuel efficiency of individual aircraft directly form the focus of analysis in this chapter. The main areas where direct fuel efficiency improvements can be made include:

- replacement of existing aircraft with more fuel-efficient new aircraft; and
- retrofitting of fuel saving technology to existing aircraft.

The BTCE used a set of simple rules in order to project the size and composition of the aircraft fleet. It was assumed that the number of seats within the fleet would grow to match growth in passenger demand, and that average aircraft size (measured in number of seats per aircraft) would increase to just over 180 seats per aircraft by 2015. In practice, decisions about the size and composition of the aircraft fleet will depend on a number of interrelated factors such as total passenger demand on each route, route structure (for example hub and spoke operations), and scheduling.

Determining the future size and composition of the aircraft fleet involved removing those aircraft from the fleet that were of retirement age and adding new aircraft of an appropriate size in order to cater for travel demand growth. The BTCE assumed that aircraft are removed from the fleet at 20 years of age. This assumption was based on historical experience. There is evidence that current aircraft will be longer lived and remain in the fleet until at least 25 years of age. Boeing (1996) estimates that passenger aircraft will be held at least 25 years before being permanently retired.

The BTCE used AVMOD to compare total emissions assuming an aircraft retirement age of 20 years, with emissions with an aircraft retirement age of 25 years. The age profile of the current aircraft fleet is such that almost all aircraft in the fleet today would be retired by 2015 assuming retirement at 25 years of age. In 2015, total aircraft emissions are likely to be very similar whether aircraft are retired at 20 years of age or 25 years of age. An aircraft retirement age of 25 years means total cumulative CO_2 equivalent emissions are only 2.5 per cent higher over the period 1995 to 2015 than with an aircraft retirement age of 20 years.

New aircraft were added to the fleet in such a way that the average number of seats per aircraft through the fleet increased gradually between 1995 and 2015. Table 13.1 summarises domestic aircraft fleet as projected by the BTCE, and table 13.2 provides a descriptive summary of the different aircraft types.

Basecase estimates

In line with BTCE (1995c, p. 232) it was assumed that total Australian domestic revenue passenger-kilometres travelled would grow by 5.4 per cent per annum between 1995 and 2015. The growth in domestic passenger-kilometres was based on an econometric relationship between gross domestic product (assumed growth of 3.2 per cent per annum), real medium distance air fares (assumed to decline by 1.3 per cent per annum) and the number of international visitors. This growth includes the number of domestic passenger trips undertaken by foreign arrivals. Estimates of basecase avtur fuel consumption are the same as in BTCE (1995c, appendix table X.3). In contrast to this Report, BTCE (1995c) did not differentiate between avtur fuel used by the military and that used for civil aviation.

Australian military aviation consumption of avtur was separated, in this Report, from domestic civil aviation avtur consumption. It was assumed that military avtur consumption would remain relatively constant until 2015 for two reasons. Because of financial constraints, the usage of military aircraft is fairly tightly controlled as aircraft are required to remain in the fleet to a certain date, and each aircraft is allowed a limited number of total flying hours before it must be retired. Secondly, pilots need to undertake a minimum number of flying hours in order to maintain their competency (Paul Edey, Department of Defence, pers. comm. 18 April 1996).

TABLE 13.1 PROJECTED NUMBER OF AIRCRAFT IN THE AUSTRALIAN DOMESTIC SCHEDULED[a] AIRLINE FLEET, BY AIRCRAFT TYPE

Type[b]	*1995*	*2000*	*2005*	*2010*	*2015*
F-50	4	4	4		
F-28 1000	1				
F-28 3000	1				
F-28 4000	7				
BAe146-100	1	1			
BAe146-200	9	9	11	12	14
BAe146-300	8	10	13	14	16
A-300	4				
A-320-200	13	19	19	19	19
B727-200	5				
B737-300	37	38	38		
B737-400	17	20	20	14	
B737-700			12	36	40
B737-800			4	18	40
B767-200	13	15	9	2	2
B767-300		4	18	44	63
B747-1/2/300		2	4	5	5
B747-400				3	7
Total	120	122	152	167	206
Seats per aircraft (fleet average)	126.5	136.5	145.6	172.2	181.9

a. Scheduled refers to aircraft operating scheduled passenger services on trunk routes.

b. F = Fokker, BAe = British Aerospace, B = Boeing; A = Airbus.

Sources BTCE estimates; Pratt 1996; Qantas pers. comm. 26 June 1996.

BTCE (1995c) basecase estimates project total domestic avtur consumption to grow by about 3.8 per cent per annum between 1995 and 2015. Assuming that military avtur fuel consumption will not increase, this implies that domestic scheduled aircraft avtur consumption is forecast to grow by approximately 4.4 per cent per annum between 1995 and 2015. Table 13.3 gives projected domestic military and scheduled aircraft avtur consumption. The projections of scheduled aircraft avtur consumption listed in table 13.3 were used to calibrate AVMOD.

TABLE 13.2 ATTRIBUTES OF SELECTED AIRCRAFT TYPES

Type[a] *(no.)*	*Seats (no.)*	*Engines*	*Range (km)*	*Build years*	*Noise category*[b]
F-50	46	2	2 055	1983	na
F-28 1000	54	2	na	From 1969	Chapter 2
F-28 3000	61	2	2 743	From 1969	na
F-28 4000	69	2	1 900	na	na
BAe146-100	64	4	3 000	1983–1992	Chapter 3
BAe146-200	76	4	2 910	1983–1993	Chapter 3
BAe146-300	92	4	2 817	1987	Chapter 3
A-300	240	2	7 955	From 1988	Chapter 3
A-320-100	150	2	4 810	From 1988	Chapter 3
A-320-200	145	2	4 810	From 1988	Chapter 3
B727-200	146	3	4 625	From 1967–1972	Chapter 2
B737-300	114	2	2 683–3 700	From 1984	Chapter 3
B737-400	136	2	2 683–3 700	From 1988	Chapter 3
B737-700	128	2	5 555	From 1997	Chapter 3
B737-800	150	2	5 555	From 1997	Chapter 3
B767-200	211	2	12 395	From 1982	Chapter 3
B767-300	250	2	11 470	From 1986	Chapter 3
B747-100	370	4	10 175–12 025	From 1969–1979	Chapter 3
B747-200	370	4	10 175–12 025	From 1970–1990	Chapter 3
B747-300	370	4	10 175–12 025	From 1983–1990	Chapter 3
B747-400	420	4	13 690	From 1989	Chapter 3

na Not available

a. F = Fokker, BAe = British Aerospace, B = Boeing; A = Airbus.

b. Refer to Glossary.

Sources *Aircraft Economics Yearbook* 1995; Frawley & Thorn 1995; *Aviation Week and Space Technology* 1996.

Technology options for jet aircraft

Under the basecase scenario the fleet average fuel efficiency improves through entry of new, more fuel-efficient aircraft and the retirement of less fuel-efficient aircraft. It was assumed that new aircraft enter the fleet either to replace an existing aircraft that has been retired or to service additional passenger growth. Details of the sequential introduction of the types and mix of aircraft applied in the analysis are given in appendix IX.

TABLE 13.3 PROJECTED BASECASE DOMESTIC AVIATION TURBINE FUEL CONSUMPTION

(million litres)

Year	*Total*	*Military*	*Scheduled*[a]
1995	1 592.8	276.7	1 316.1
1996	1 652.8	285	1 367.8
1997	1 714.6	285	1 429.6
1998	1 778.3	285	1 493.3
1999	1 847.3	285	1 562.3
2000	1 920.7	285	1 635.7
2001	1 996.6	285	1 711.6
2002	2 075.3	285	1 790.3
2003	2 156.9	285	1 871.9
2004	2 241.4	285	1 956.4
2005	2 328.5	285	2 043.5
2006	2 418.7	285	2 133.7
2007	2 512.1	285	2 227.1
2008	2 608.9	285	2 323.9
2009	2 709.2	285	2 424.2
2010	2 812.4	285	2 527.4
2011	2 919.3	285	2 634.3
2012	3 030.0	285	2 745.0
2013	3 144.6	285	2 859.6
2014	3 263.2	285	2 978.2
2015	3 385.9	285	3 100.9

a. Scheduled refers to aircraft operating scheduled passenger services on trunk routes.

Source BTCE estimates.

Fuel consumption by aircraft used predominantly for Australian domestic scheduled passenger services on trunk routes in 1990 ranged from 16.7 to 56.6 seat-kilometres per litre (BTCE 1992a, p. 76).

Energy efficiency gains are possible through technological improvements to engine propulsion systems, use of airframes built from lighter materials and designed to reduce drag, and through use of larger aircraft with higher seating capacity. A more detailed description of the potential technology options is given in appendix IX.

The technology options considered in this analysis are based largely on the technology scenarios outlined by Greene (1995). Greene (1992, p. 557) estimates the median seat-miles per gallon improvement of 83 per cent for propfan propelled aircraft and 70 per cent for ultra high-bypass engine aircraft (see appendix IX for further details). The minimum and maximum efficiency improvements are 57 per cent and 110 per cent for propfan aircraft, and 43 per cent and 97 per cent for ultra high-bypass ducted fans. The individual technology options and resultant fuel efficiency improvement outlined by Greene (1992) are listed in appendix IX.

Two alternative technology scenarios were considered: a low efficiency scenario and a high efficiency scenario for new generation ('post-2000') aircraft technology (table 13.4). Under the basecase scenario it was assumed that the fuel efficiency of the aircraft fleet only improves through the retirement of older aircraft and entry of new aircraft. New aircraft were assumed to utilise the same technology as aircraft currently produced. More advanced technological options did not form part of the basecase.

The post-2000 technology scenario is identical to the basecase, except that more advanced ('post-2000') technologically enhanced aircraft are assumed to enter the fleet from 2005 onwards. Under the low efficiency technology scenario it is assumed that: new generation aircraft start being introduced into the fleet between 2005 and 2009 are 20 per cent more fuel efficient than the comparable 1990s generation aircraft they replace; aircraft introduced into the fleet between 2010 and 2014 are 30 per cent more fuel efficient; and by 2015 new generation aircraft are 45 per cent more fuel efficient than the comparable 1990s generation aircraft. Under the high efficiency technology scenario it was assumed that new generation aircraft are introduced into the fleet as per the low efficiency scenario, plus aircraft introduced between 2005 and 2009 being 20 per cent more fuel efficient than comparable 1990s generation aircraft, and aircraft introduced from 2010 onwards being 70 per cent more fuel efficient than 1990s generation aircraft.

To keep the analysis simple, it was assumed that the composition (in terms of the type, size and number of aircraft) of the fleet was identical under each of the different technology scenarios. In practice, long lead times are required to develop new aircraft technology, and aircraft manufacturers would require orders in advance of construction. With advance notice of a new, possibly cost saving technology being on offer in the near future, airlines might choose to alter the time and pattern of aircraft acquisition.

TABLE 13.4 AIRCRAFT FUEL EFFICIENCY TECHNOLOGY SCENARIOS

Scenario	*Definition*
Basecase	No new generation aircraft introduced until after 2015. No fuel efficiency improvements to the existing fleet (such as retrofitting of technology). Improvements in fuel efficiency occur only through introduction of more fuel-efficient aircraft and retirement of less efficient aircraft. Aircraft are assumed to be retired from the Australian fleet at 20 years of age.
'Low efficiency' improvement	More fuel-efficient aircraft are introduced into the fleet from 2005 onwards. Aircraft entering the fleet in 2005 are assumed to be 20 per cent more fuel efficient than 1990s generation aircraft of comparable size, aircraft entering the fleet in 2010 are assumed to be 30 per cent more fuel efficent than 1990s generation aircraft, and aircraft entering the fleet in 2015 are assumed to be 45 per cent more fuel efficient than 1990s generation aircraft. No fuel efficiency improvement to the existing aircraft in the fleet. Aircraft are assumed to be retired from the fleet at 20 years of age.
'High efficiency' improvement	More fuel-efficient aircraft are introduced into the fleet from 2005 onwards. Aircraft entering the fleet in 2005 are assumed to be 20 per cent more fuel efficient than 1990s generation aircraft of comparable size, and aircraft entering the fleet from 2010 onwards are assumed to be 70 per cent more fuel efficient than existing aircraft of comparable size. No fuel efficiency improvement to the existing aircraft in the fleet. Aircraft are assumed to be retired from the fleet at 20 years of age.

Sources Greene 1992, p. 565, 1995, pp. 3–6, 11–14.

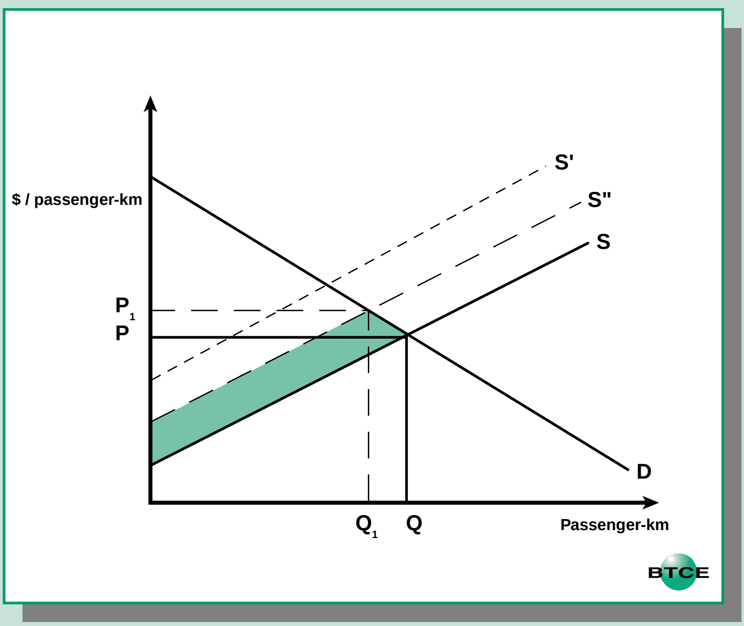
Costs of aviation technology options

The earlier uptake of more fuel-efficient aircraft technology would have important financial implications for airlines and air travellers.

Introduction of aircraft with post-2000 type technology means higher capital expenditure for airlines. Post-2000 technology options will improve aircraft fuel efficiency and lower overall fuel consumption, resulting in fuel cost savings to airlines. The total economic cost of introducing post-2000 aircraft technology is estimated as the additional cost of the new technology less any fuel cost savings attributable to the new technology. Costs are expressed as net present values in 1995–96 dollars, using a 10 per cent discount rate.

Figure 13.2 shows the partial equilibrium measure of the costs of new aircraft technology. Initially, the supply curve is at S and demand at D. Introduction of post-2000 aircraft would raise the cost per passenger-kilometre to S′. But savings in fuel expenditure would reduce costs, so that the cost per passenger-kilometre rises only to S″. The net economic cost is given by the shaded area and is equal to the additional resource cost of those aircraft trips still undertaken, plus the value of air trips forgone as a result of the increase in average trip costs. Conversely, if the present value of total fuel cost savings outweighed the technology costs then the net economic gain would be a similarly shaped area to the right of the original supply curve, S.

FIGURE 13.2 PARTIAL EQUILIBRIUM MEASURE OF ECONOMIC COST



Source BTCE estimates.

In the case where the costs of post-2000 technology outweigh the fuel cost savings, consumer surplus would be reduced by the increase in air fares, but part of this consumer surplus loss is a direct transfer to airlines, so that the total (partial equilibrium) economic cost is given by the shaded area in figure 13.2.

To measure the full economic effects, it is also necessary to consider any economic effects in markets for substitute or complementary products to air travel, where there exist distortions such that price differs from social marginal cost. Aviation fuel taxes and the public costs of noxious emissions and noise are potential distortions. Domestic aviation (avtur) fuel taxes were abolished in 1988, and were replaced with air services charges. In 1994, avtur customs and excise duties of 1.46¢/L were implemented to contribute to expenditure on safety (AIP 1995, p. 19). It was assumed that the customs and excise duty was a user charge, and therefore not a distortionary levy. Expenditure on airport and air navigation facilities was assumed to be unrelated to the introduction of new aircraft technology.

Externalities associated with a shift to more fuel-efficient aviation technology include noise and noxious emissions. According to Somerville (1993, p. 162), advances in engine technology (particularly the high-bypass turbofan engine) and aircraft design have led to significant reductions in the noise generated. The increasing proportion of twin-engine aircraft is also expected to contribute to the continuing improvement of noise levels around most airports until at least the late 1990s (Somerville 1993, p.162). Estimating costs of these reductions in noise was hindered by the lack of appropriate information, and they were therefore not considered in the analysis. The effect of any change in noxious emissions was also not analysed because of the lack of sufficiently reliable information.

The total cost of aviation technology was derived using 1995 aircraft prices (ITA 1995, pp. 28–29). The technology costs for the post-2000 aircraft scenarios were assumed to be 20 per cent more expensive for aircraft built between 2005 and 2009 and 45 per cent more expensive for aircraft built after 2010 under the low efficiency scenario, and 20 per cent and 70 per cent more expensive under the high efficiency scenario, compared with 1995 aircraft prices. Aircraft prices were assumed to remain constant in real terms throughout the study period. There is very little information available about the cost of new aircraft technology. Greene (1992, p. 548) provides some information on the likely cost of new technology: '… advanced unducted fans … cost twice as much (US$10 million versus US$5 million per US$30–40 million aircraft) as present generation high bypass engines'.

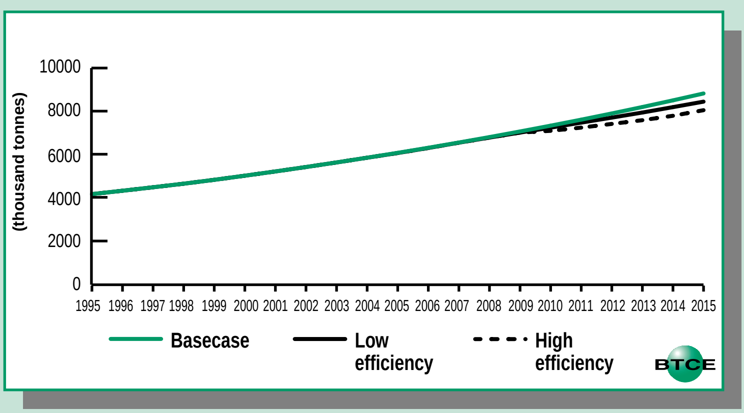
Savings in fuel expenditure were computed using the estimated changes in fuel consumption derived from AVMOD, and the average 1995 price of aviation fuel (55.5 cents/litre) given in BTCE (1996b). The price of aviation fuel was assumed to remain constant in real terms to 2015.

Cost estimates presented are the present values (1995–96 $) of cumulative costs for snapshot years up to the year 2015. Costs were counted only in the year that they occur. For post-2000 technology options, the additional cost of leasing new aircraft was used to measure technology costs. Post-2000 technology options are introduced into the aircraft fleet beginning in 2005. The additional leasing cost of new technology means that the timing of fuel cost savings attributable to the new technology more closely accords with the timing of capital costs.

RESULTS

Based on the estimates obtained from AVMOD and assumed growth in domestic passenger demand of 5.4 per cent per annum, basecase emissions from scheduled domestic aviation activity are expected to increase by 112 per cent between 1996 and 2015 (an increase of 3.8 per cent per annum) (figure 13.3). If new generation aircraft were to be introduced (the post-2000 technology scenario), there would be a

FIGURE 13.3 TOTAL CO_2 EQUIVALENT EMISSIONS UNDER FUEL-EFFICIENT TECHNOLOGY SCENARIOS FOR DOMESTIC SCHEDULED AIRCRAFT



Source BTCE estimates.

reduction in emissions growth from 2005, but total greenhouse emissions would still increase by 103 per cent between 1995 and 2015 under the low efficiency scenario and by 94 per cent under the high efficiency scenario (an increase of 3.6 per cent and 3.4 per cent per annum, respectively).

To simplify the analysis, it was assumed that the fuel efficiency improvement in avgas powered aircraft would be equal to the fuel efficiency improvement of avtur powered aircraft. The BTCE considered this a reasonable assumption given that avgas powered aircraft contribute only 5 per cent of total greenhouse emissions from domestic aviation.

The results suggest that the introduction of post-2000 aircraft technology from 2005 has the potential to reduce emissions by only 4.5 per cent below the basecase level under the low efficiency scenario and 10 per cent under the high efficiency scenario in 2015. This represents a 1 per cent reduction in cumulative CO_2 equivalent emissions under the low efficiency scenario and a 3 per cent reduction under the high efficiency scenario between 1995 and 2015. Even under the optimistic scenario of new technology entering the fleet from 2005, however, total CO_2 equivalent emissions will continue to increase in absolute terms. The level of emissions under each of the scenarios is shown in figure 13.3, with actual figures given in **appendix table IX.2**.

For post-2000 technology options, the present value (1995–96 $) of the total net cost is quite high, making new technology a costly measure for reducing greenhouse gas emissions, with the reduction in emissions occurring only after 2005. The cumulative total, marginal and average costs of each of the options are given in table 13.5.

Sensitivity testing

Sensitivity analysis was performed on a number of aspects of the aircraft technology cost results. Alternative discount rates of 5 per cent (low), 10 per cent (basecase) and 15 per cent (high) were applied. The size of the discount rate did not affect the pattern of results.

Sensitivity analysis was also performed on the size of the assumed capital costs of the post-2000 technology scenarios. The sensitivity analysis considered the increase in total capital costs of 50 per cent less and 50 per cent higher than the assumed median increase in capital costs. The analysis suggests that the technology would have to be significantly cheaper than is assumed here, to be a 'no regrets' measure.

TABLE 13.5 TECHNOLOGICAL IMPROVEMENTS FOR DOMESTIC AIRCRAFT: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1) Intensity[b]	*(2)* Cumulative reduction: CO_2 equivalent *(thousand tonnes)*	*(3)* Change in cumulative reduction: CO_2 equivalent *(thousand tonnes)*	*(4)* Social cost of cumulative reduction *($ thousand)*	*(5)* Change in social cost *($ thousand)*	*(6)* Average social cost[c] *($ per tonne)*	*(7)* Marginal social cost[d] *($ per tonne)*
1996 to 2005						
Low efficiency	10	10	3 970	3 970	397	397
High efficiency	10	0	3 970	0	397	0
1996 to 2010						
Low efficiency	200	200	99 000	99 000	495	495
High efficiency	300	100	143 000	44 000	477	440
1996 to 2015						
Low efficiency	1 500	1 500	248 000	248 000	165	165
High efficiency	3 300	1 800	490 000	242 000	149	134

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. The assumptions underlying the different intensity levels are outlined in table 13.4.

c. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates.

The BTCE has assumed growth in domestic passenger demand (in seat-kilometres) of approximately 5.4 per cent per annum, based on the assumptions that GDP grows at approximately 3.3 per cent per annum and real air fares fall by 1.4 per cent per annum between now and 2015. Under the basecase, this implies that CO_2 equivalent emissions from domestic aviation will grow by 3.8 per cent per annum.

Industry sources suggest that the BTCE's assumed growth in domestic passenger demand is higher than the industry expects. If passenger demand were to grow by only 4.5 per cent per annum, in contrast to 5.4 per cent per annum, growth in total CO_2 equivalent emissions would be approximately 2.9 per cent per annum under the basecase, and total

CO_2 equivalent emissions would be approximately 8023 thousand tonnes in 2015, or 9 per cent less than they would be if demand grew by 5.4 per cent per annum.

EQUITY ISSUES

New aircraft technology would raise the capital cost of aircraft for airlines but would offer savings in fuel costs, and possibly other operating costs.

Any additional net costs incurred by domestic airlines would increase average flight costs, part of which would be passed on to consumers in the form of increased average fares with the remainder borne by airlines through reduced profits. Any reduction in complementary services (due to lower demand for air travel), including road transport to airports, would reduce government revenues from fuel excise.

The effects on government revenue would also depend on the extent of taxes and charges already imposed on airlines. There is a small customs and excise duty on aviation fuel, intended to cover the costs of aviation safety services. Introduction of fuel-efficient technology would reduce the demand for aviation fuel and reduce government revenue for spending on aviation safety.

Government expenditure on air travel may fall, but this simply involves a transfer from government to airlines, with no net welfare effect for the community as a whole.

TABLE 13.6 COMPOSITION OF CUMULATIVE TOTAL SOCIAL COSTS[a] OF TECHNOLOGICAL IMPROVEMENTS FOR DOMESTIC AIRCRAFT TO 2015

($ million)

	Low efficiency scenario	*High efficiency scenario*
Producer	83	163
Consumer	165	327
Government	na	na
Externalities	0	0
Total	248	490

a. Costs are expressed in net present values (1995–96 $) using a 10 per cent discount rate.

Source BTCE estimates.

There is evidence that some technology options would reduce aircraft noise, which would offer some improvement in welfare for people living close to airports or under flight paths. Some technology options, like unducted propfans, may increase local noise. The overall impact is too uncertain to analyse at this stage.

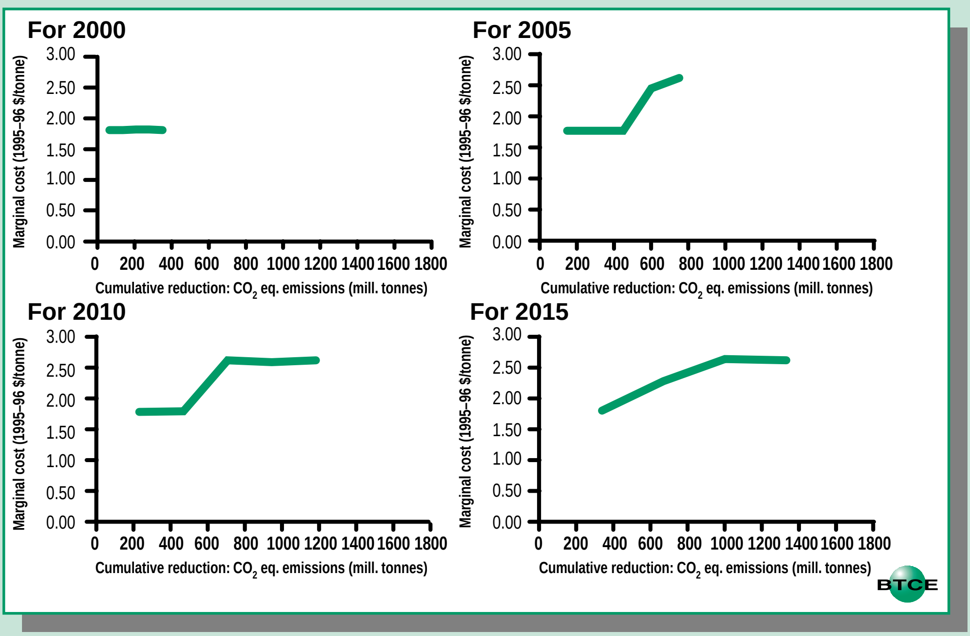
Table 13.6 provides estimates of who bears the cost of introducing new technology aircraft into the fleet. The cost to air travellers (consumers) and the cost to airlines (producers) depends on the elasticity of air travel demand and supply. The higher the elasticity of supply relative to demand, the greater the share of the cost faced by air travellers. The estimates in table 13.6 are based on the assumption that in the long run, the elasticity of supply is greater than the elasticity of demand, so that the economic cost of new aircraft technology falls in greater part on consumers.

...AT A GLANCE

Removal of CO_2 from the atmosphere is an alternative to reducing emissions. Fuel wholesalers could be required to reclaim all CO_2 emitted by the transport sector by planting trees. About 2 million hectares (about 22 per cent of Australian land suitable for planting trees) would be required to sequester all transport emissions up to the year 2015. Marginal costs per tonne of CO_2 absorbed range from $1.80 in 2000 to only $2.93 in 2015.

- As wood decays, CO_2 is released into the atmosphere, re-emitting the carbon originally stored through photosynthesis. Tree planting is thus often seen as a short-term 'buying time' option for reducing greenhouse gases.
- But it is possible to sequester CO_2 on a permanent basis by continually planting trees into the future to compensate for decay. An innovative 'steady state' analysis — which took into account three different decay rates for wood products, carbon stored in trunks, roots and foliage, land costs, and revenue from timber sales — was used to estimate costs.
- On average, seven trees would need to be planted *each year* for each car in the Australian fleet. To ensure permanent removal of the CO_2 from the atmosphere, the trees would need to be replanted after harvesting.

FIGURE 14.1 PLANTING TREES: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 14 PLANTING TREES TO SEQUESTER CARBON DIOXIDE

An alternative to reducing emissions from fossil fuels used by vehicles is the creation of a ‘sink’ to reclaim carbon dioxide (CO_2). If the cost of reclaiming emissions is borne by the seller or user of the fuel, this alternative becomes a ‘polluter pays’ approach to reducing greenhouse gases.

It is assumed that wholesalers of all fossil fuels used domestically in vehicles are required to reclaim the CO_2 emitted. Wholesalers could reclaim CO_2 emissions through a range of measures including pumping it under the ocean or into oil wells, planting trees, storing it in tanks, or freezing it. Ormerod et al. (1993) indicate that planting trees is a relatively low cost option. Given the relatively large area of land available for planting trees in Australia, and because tree plantations yield revenues that can be set off against the cost of reclaiming carbon, it has been assumed that wholesalers of fossil fuels would choose forestry as a least-cost option to reclaim CO_2 in fulfilment of government requirements. Because the reclamation requirement assumes permanent sequestration, the policy instrument is not merely one of ‘buying time’ like many other tree planting scenarios examined in contemporary greenhouse studies.

The concept is analogous to the German Duales System which requires supermarkets to accept for recycling the packaging in which their goods are sold. In the case of CO_2 emissions, the carbon content can be considered as ‘packaging’.

While the many individual end users of the fuels could be required to reclaim the carbon, it has been assumed that overall transactions costs are minimised by imposing the obligation on wholesalers.

An implicit assumption is that wholesalers will have a greater incentive to minimise net costs than a government-run forestry program. Wholesalers are assumed to plant a relatively fast growing species like

Pinus radiata, to sell the stem wood, and to manage the plantations on a commercial basis.

A tree planting instrument is particularly attractive in Australia because it complements government reforestation initiatives such as the One Billion Trees Program. Where plantation softwoods are a substitute for native hardwoods, the instrument could also reduce the need to log 'old growth' native forests.

It may be appropriate for the community (through the government) to pay the fuel wholesalers for spin-off social benefits produced by their plantations. This aspect has not been considered in this Report because such payments are currently not normal in other commercial operations. Benefits such as improved water quality, reduced soil erosion, species protection and enhanced biodiversity would also not be fully realised under conditions of periodic harvesting.

There are several options for the use of wood produced in plantations. Mature trees could be left standing in a forest, but the amount of carbon sequestered would be a one-off increase. The stored carbon would gradually be released into the atmosphere as the forest aged and decayed. Sequestration of carbon could be increased only by planting more land.

Many studies that examine forestry as an option for creating a 'carbon sink' analyse wood only in terms of its decay rate (and hence storage time for carbon). However, wood is a renewable source of energy which can be substituted for fossil fuels. To the extent that less fossil fuel is used, the use of replaceable firewood represents an 'opportunity benefit' in reducing greenhouse gas emissions. The amount of fossil fuel conserved would reflect the contribution of forestry to reducing greenhouse gas emissions. There has recently been a renewed interest in coppicing as a means of increasing the rate at which biomass can be generated for use as fuel (Read 1994).

An increased availability in Australia of softwood such as *Pinus radiata* is likely to be reflected in more opportunities for substitution of wood for concrete and steel, particularly in flooring and frames of residential buildings. Concrete and steel production require fossil fuel inputs, and production of concrete itself produces CO_2. Substitution of wood for concrete and steel would therefore indirectly sequester carbon to the extent of any fossil fuel not used. Maclaren (1994, p. 14) cites estimates by Honey and Buchanan (1992) indicating that 59 GJ of energy is required to manufacture one tonne of structural steel, compared with only 2.4 GJ per tonne of treated timber.

Potential substitution of wood for fossil fuels or other products was not analysed. To do so satisfactorily would require a detailed carbon budgeting approach taking into account, among other things, the precise extent of substitutability and related energy usage, including fossil fuel used to transport raw material inputs and to distribute final products. A 'program' analysis of this sort was beyond the scope and intent of this study.

METHODOLOGY

The amount of carbon that will be emitted from fuel used in transport in any year up to 2015 is known from basecase projections of CO_2 emissions **(appendix III)**.

In practice, fuel is not completely oxidised into CO_2, but methane (CH_4) and carbon monoxide (CO), which are also produced, break down on average within 11 years and 3 months, respectively, into CO_2. For example, in 1996, 68.3 million tonnes of CO_2 are expected to be emitted from domestic transport (road, rail, sea and air) on a fully oxidised basis (appendix III), so that the amount of carbon emitted will be 18.6 million tonnes ($12/(12+16+16) \times 68.3$ where 12 and 16 are the atomic weights of carbon (C) and oxygen (O) respectively).

Knowledge of the amount of carbon that can on average be sequestered per hectare by a pine plantation that is continually harvested and replanted in perpetuity permits estimation of the land area required to be planted to offset all or part of the CO_2 emitted in a given year. Estimation of the costs associated with establishing and maintaining successive plantings provides sufficient information to calculate the marginal cost of sequestering carbon.

Over a long period, a natural, unharvested (old growth) forest may be assumed to reach a state of equilibrium where the total amount of wood or carbon per unit area is, on average, constant. In this 'steady state' equilibrium, the rate of growth (addition to the stock of wood) and the rate of decay (depletion of wood) would be equal.

A natural forest comprises trees of different ages. In the case of plantations, individual annual plantings involve trees of identical ages, but the total plantation estate can be considered a forest of trees of mixed ages. Whereas trees in a natural forest will die at a biological limit, it has been assumed that the trees in a plantation estate will be harvested at 35 years of age, with immediate replanting of the land. The concept is illustrated in figure 14.2, which shows plantation strips of 1 hectare corresponding to one year's planting, with each strip containing trees of uniform age. Taking all the strips together, even in a different sequence to that shown in figure 14.2, results in a 'natural' mix of tree ages.

The fact that timber is harvested, and that it decays in locations away from the forest (for example, as paper), does not preclude envisaging the estate as a mixed-age natural forest. The difference between a natural mixed-age forest and a forest in a 'steady state' is that the steady state amount of carbon sequestered at any point in time in a plantation estate may be higher than in a natural forest. In particular, the rate of decay of timber derived from a plantation is slower because timber stored as frames of houses, for example, decays more slowly than a log exposed to the elements in the forest. Further, commercially grown plantation timber is often cut roughly at the time of greatest average growth rate rather than being permitted to grow more slowly to maturity. A greater amount of carbon is thus 'harvested' over time in plantations than in a natural forest.

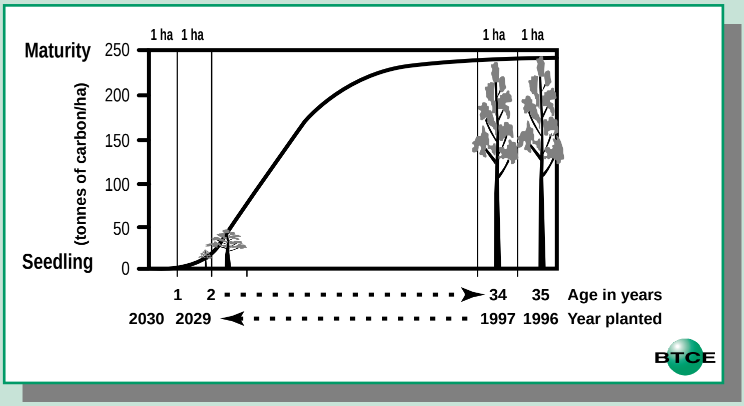
Carbon sequestration in standing timber

Figure 14.2 illustrates the sequestration of carbon in standing timber. The estate shown is assumed to be a species with growth characteristics similar to *Pinus radiata* harvested when 35 years old. At the end of the year 2030, the largest trees (planted in 1996) are harvested. The '1996' area is replanted during 2031. A new area is also planted in 2031 to soak up emissions from fuel used in that year. At the end of 2031, the '1997' plantation is harvested; it is replanted in 2032 and a new plantation for year 2032 emissions is planted at the same time.

In practice, therefore, the total area of the plantation estate will need to expand each year (to the extent of land availability) because of the assumption that fuel wholesalers are required by the government to permanently reclaim some or all of the CO_2 emitted each year.

Several authors note a lack of consensus among foresters about the best form of a mathematical function to describe tree growth, possibly because of the lack of data and limited understanding of the growth process (Zeide 1993; Clutter et al. 1983; Leech & Ferguson 1981). BTCE (1996c, pp. 25–32) describes and discusses various mathematical functions that have been used, or considered for use, in modelling tree growth.

FIGURE 14.2 SEQUESTRATION OF CARBON IN PLANTATIONS



Source BTCE estimates.

Zeide (1993, p. 604) shows that all but the Weibull equation can be reduced to one of two basic growth functions, differing essentially in only the decline component. Because of its mathematical tractability, and the fact that it is used by a number of forestry researchers, the Gompertz function was adopted by the BTCE to describe the yield of a plantation estate over time. Its form may be expressed as:

$$V = V_m e^{-be^{-kt}} \qquad (1)$$

where V is the volume or weight of wood or carbon, V_m is the maximum or saturation level of V, t is time, b and k are constants, and e is the base of the natural logarithm.

At any point in time the average stock of carbon sequestered per hectare in a plantation estate that accords with this yield function is given by:

$$V_m \frac{\int_{t=0}^{t_n} e^{-be^{-kt}} \, \mathrm{d}t}{t_n} \qquad (2)$$

where t_n is the rotation period or time between successive harvests.

The rotation period was taken as 35 years and the carbon sequestered (*V*) in a 35-year-old *Pinus radiata* plantation was conservatively taken as 243 tonnes per hectare (R. Boardman, pers. comm. 9 October 1995). The possible growth-enhancing effect on trees of increased concentrations of atmospheric CO_2 has not been taken into account in this study. This CO_2 'fertilisation' effect is not presently well understood (see BTCE 1996c, pp. 53–54).

Summation of carbon mass per hectare for each year from planting to harvesting, divided by 35, produces an average amount sequestered at any point in time of 176 tonnes of carbon per hectare for the plantation estate as a whole. Unfortunately, data were not available to permit full, independent estimation of the parameters of the Gompertz function. It was necessary to assume that the 35-year value of 243 tonnes per hectare (assuming that the point of inflection of the Gompertz yield curve occurs when the forest is eight years old) was equivalent to the saturation level V_m, giving values of $b = 8.49$ and $k = 0.27$.

Pinus radiata will not grow well on all the land considered in this study. In some areas, planting of other types of pine would be necessary and there may also be areas that would have to be planted with species other than pine. This Report assumes the planting of generic trees whose productivity approximates that of *Pinus radiata*.

The productivity of land for generic tree plantations with similar growth characteristics to *Pinus radiata* varies widely across Australia. The analysis took account of varying land productivity to some extent by classifying land into four groups and applying two different yield values to them (BTCE 1996c, pp. 43–51). The productivity of 243 tonnes per hectare—based on yield class 3 in South Australia (R. Boardman, pers. comm. 9 October 1995), was assigned to land with medium plantation capability and low or medium agricultural intensity. Based on data in yield tables (Lewis, Keeves & Leech 1976), a 14 per cent premium was added to land with high plantation capability and low or medium agricultural intensity, resulting in a productivity of 277 tonnes per hectare. These two levels of land productivity were matched with a range of land costs to generate a planting order of different areas of land in each state and territory (BTCE 1996c, pp. 43–51).

Decay of wood products

Decay occurs according to the standard formula:

$$V_t = V_f \, e^{-\gamma} \qquad (3)$$

giving:

$$\frac{dV_t}{dt} = -\gamma V_f e^{-\gamma t} \quad (4)$$

where V_f is the stock of wood or carbon at the time the forest is felled, and V_t is the stock at any time t, so that:

$$\frac{1}{V_t} \cdot \frac{dV_t}{dt} = -\gamma \quad (5)$$

The proportionate rate of decay at any time is thus given by the constant γ, and indicates the proportion of a product that decays each year.

Decay is normally expressed in terms of half lives, so that $V_t/V_f = 1/2$ and substituting this in equation (3) yields:

$$e^{-\gamma t} = 1/2 \quad (6)$$

from which

$$\gamma = 0.693/t \quad (7)$$

where t is in half-life values.

If $t = 1$ (assumed below in the case of short-lived products such as paper), then $\gamma = 0.69$, meaning that almost 70 per cent of paper will decay during the course of the first year after harvesting, and a further 70 per cent of the remaining 30 per cent will decay during the second year, and so on.

The 'steady state' equilibrium approach

The concept of a 'steady state' involves the assumption that the forest is replenished at the same rate as it decays. This assumption means that the annual addition to the wood stock (average rate of growth of the forest) equals the annual rate of decay.

It was assumed that the wood stock can be classified into three product fractions which decay at different rates after harvesting, so that:

$$\gamma_i S_i = p_i A \quad (8)$$

where p_i is the fraction of wood product i (i = 1, 2, 3), S_i is the stock of product i per hectare at any time, γ_i is the decay constant for p_i at any time and A is the average annual growth rate per hectare of the forest at any time ($A = V_m/t_n$).

The total carbon sequestered in harvested, but non-decayed wood products is given by

$$\sum_{i=1}^{3} S_i = \sum_{i=1}^{3} \frac{p_i A}{\gamma_i} \qquad (9)$$

Following the general approach of Maclaren and Wakelin (1991), it was assumed that the generic trees grown form three product fractions: short life (for example, paper products), medium life (for example, particle board) and long life (for example, timber used in building construction). On the basis of available data on the uses of softwood (BTCE 1996c, pp. 37–39), these fractions were assumed to form 47, 29 and 24 per cent of the total biomass ($p_1 = 0.47$, $p_2 = 0.29$, $p_3 = 0.24$) with half lives of 1, 5, and 10 years respectively. Their respective decay constants (γ) are therefore 0.69 (0.69/1); 0.14 (0.69/5); and 0.07 (0.69/10).

The average per hectare stock of undecayed biomass is thus determined as:

$S_1 + S_2 + S_3 = 4.7 + 14.5 + 24.0 \approx 43$ tonnes per hectare

The total amount of carbon sequestered at any time in a steady state plantation estate is the sum of the carbon contained in (live) standing trees, as well as the undecayed stock of biomass and wood products derived from harvested timber: equation (2) plus equation (9). This sum was taken as 176 tonnes per hectare in standing timber and 43 tonnes per hectare in undecayed wood product, totalling 219 tonnes per hectare.

A steady state equilibrium situation will only be attained after many years. However, in this analysis the steady state carbon content of 219 tonnes per hectare has been applied to carbon sequestered in the period 1996 to 2015. The BTCE approach therefore assumes that the steady state quantity of carbon is attained much sooner than would actually occur. The implications of this assumption are that the amount of carbon sequestered over the period 1996 to 2015 is overestimated and the total and marginal costs per tonne of carbon sequestered are underestimated. Over the longer term, this would be less relevant because plantations are assumed to be kept under forest in perpetuity.

Possible changes in soil carbon storage associated with forest clearing, reforestation and fire practices were not considered because the uncertainties involved in terms of current knowledge were too great to generate reliable figures. It is nevertheless likely that a commercial wholesaler of fuel forced by the government to maximise sequestration of carbon would implement plantation methods that minimised soil disturbance in order to be able to claim a greater amount of carbon sequestration.

Costs and revenues of plantations

Foresters recognise at least four different types of rotation (Kula 1988):

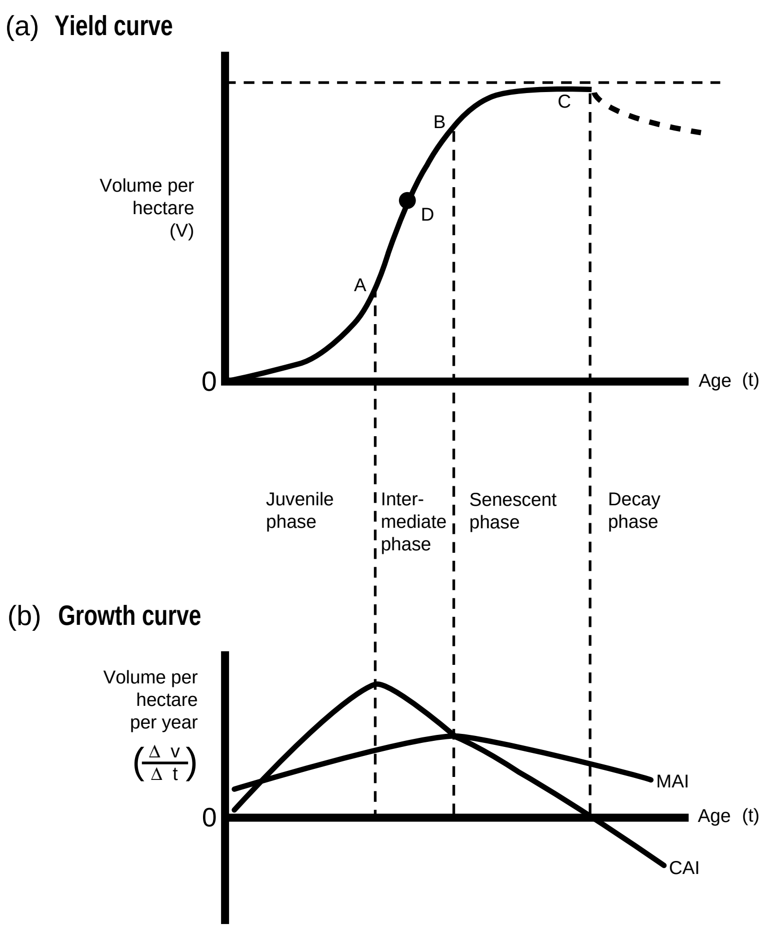
- *technical rotation* refers to the point in time when the plantation meets the specification of a given market (for example veneer logs, saw logs, pulp wood);
- *rotation for maximum volume production* occurs when the mean annual increment is at its maximum;
- *rotation for natural regeneration* is determined by the age at which maximum viable seed is produced;
- *financial rotation* is the period which produces the maximum discounted net revenue.

Growth and yield cycles for plantations are often illustrated in the literature (for example, Clutter et al. 1983) in terms similar to figure 14.3. Maximum harvestable volume occurs at point *C*, just before senescence. Maximum annual growth rate occurs at point *A*, after which the annual rate of growth slows. At point *B*, where a ray drawn from the origin would be tangential to the yield curve, the average rate of growth per hectare per year is at a maximum.

None of these points is necessarily economically optimal for harvesting. The economically optimal range for harvesting usually lies between points *A* and *C*. The economic objective is to maximise the net present value of revenue per hectare per year. This objective is achieved when the rate of change in the value of the forest just equals the opportunity cost (rate of return) of capital invested. Maintaining the plantation involves a cost in the form of the interest forgone on the revenue that could be earned by selling the timber. If a zero discount rate were applied, the optimum rotation would generally correspond to the point where maximum biomass is obtained (point *C*). However, if a positive non-zero discount rate is applied, harvesting should occur before maximum biomass is attained.

If further crops are to be planted, there is an additional opportunity cost involved in postponing the harvesting of the current stock, because of the

FIGURE 14.3 FORESTRY YIELD AND GROWTH CURVES



A = Inflection point $\left(\frac{d^2V}{dt^2} = 0\right)$

B = Optimal harvesting age in terms of physical product (yield)

C = Maximum biological yield $\left(\frac{dV}{dt} = 0\right)$

MAI = Mean annual increment

CAI = Current annual increment

Source BTCE.

potential returns from future harvests (RAC 1992, p. Q4). Consequently, in the case of continual rotations, it is necessary to take account of the relatively faster growth that occurs during the early part of each rotation. The maximum yield per hectare per year occurs when the average rate of growth is at a maximum (point *B*). Hence, when a positive discount rate is applied, the optimal economic rotation would be reduced, and would correspond to a point to the left of *B* such as *D*.

The use of a single cycle is not the correct approach for calculating the net present value for a project of long duration that can be replicated in perpetuity. In a review of the issue, Samuelson (1976, p. 470) points out that even eminent economists such as Hotelling, Fisher and Boulding have erroneously used the single-cycle approach instead of a steady state equilibrium of indefinite replantings.

The formula used to calculate the present value of an infinite cycle of planting and harvesting over a 35 year rotation is:

$$PVC = (PVC + V_l) + \frac{PVC}{(1 + r)^{35} - 1} \qquad (10)$$

where *PVS* is the net present value of the infinite cycle of planting, *PVC* is the net present cost of a single cycle (establishment and annual recurring costs minus revenue from stumpage), V_l is the value of land (purchase price per hectare) and *r* is the rate of interest. BTCE (1996c, pp. 55–58) provides details of the derivation of equation 10.

If fuel sellers are to claim credit for carbon sequestered in terms of both standing timber and undecayed product, it is arguable that revenues and costs should take into account the process of turning trees into timber products. If this view were accepted, then a full carbon budgeting analysis would need to be conducted, including costs and emissions involved in delivery of wood products to final consumers. It is equally arguable that inclusion of downstream effects such as transport of wood products would risk double counting and circularity in analysis. Hence, partial equilibrium analysis was adopted to permit comparisons of a carbon ‘sink’ with other policy instruments.

Establishment and recurrent costs of planting were derived from RAC (1992) and are set out in BTCE (1996c, pp. 41–42). To compensate for the expected decline in land productivity over many planting cycles, it was assumed that land preparation and fertilising costs of $465 (N. Byatt, ACT Forests, pers. comm. 21 November 1995) are incurred at the beginning of each 35-year cycle after the first cycle (that is, excluding the first cycle).

Land costs are normally excluded from greenhouse studies involving forestry instruments, mainly because of the lack of suitable data. Unpublished data on the location of land suitable and available for growing hardwood species in each state and territory, purchased from the Commonwealth Scientific and Industrial Research Organisation (CSIRO), were used in this study. It can be assumed that these data would not differ appreciably for softwoods such as pine (T. Booth, CSIRO, pers. comm. 26 April 1995).

Values of land suitable for softwood plantations in Australia were estimated from information provided by Valuer-General offices in each state and territory, forestry authorities and other sources. Data on land values are set out in BTCE (1996c, pp. 49–50).

The stumpage (trees sold as standing crop) value used was $32 600 per hectare. This value was derived by adjusting the stumpage value in RAC (1992, p. P4) to 1995–96 $ using timber price indexes (ABARE 1994, p. 121).

Arguments are sometimes advanced in the literature for low discount rates of around 3–5 per cent to be applied to forestry on the basis that it is a long-term investment. Nevertheless, normal investment analysis should apply to forestry because it is no different from any other investment that uses scarce resources. This view is supported by authors like Samuelson (1976) and Price (1976). Indeed, Price (1976, p. 100) observes that economists might argue that the long growing period increases uncertainty, thus requiring a more stringent test of viability. As the instrument analysed in this study relates to forestry investment by fuel wholesalers on a commercial basis, a rate of discount of 10 per cent has been applied (identical to the rate used in other chapters in this Report). Marginal costs were tested for sensitivity to discount rates of 5 and 15 per cent.

Planting order

A planting order for land available for plantations in Australia was derived using both yield data and a range of land values for each state and territory. The planting order ensures that the more cost-effective land is planted earlier. BTCE (1996c, pp. 43–52) describes the procedure adopted to derive the planting order set out in table 14.1.

TABLE 14.1 ORDER[a] OF ACQUISITION AND PLANTING OF LAND FOR FORESTRY

Location	*Land category[b]*	*Land available[a] (thousand hectares)*	*Land value ($/hectare)*
Qld	21	103	800
NT	31	355	1 000
Tas.	21	4	1 000
NSW	21	141	1 000
Tas.	31	11	1 250
Tas.	22	12	1 250
SA	21	10	1 300
Vic.	21	87	1 300
Tas.	32	3	1 500
NT	32	13	1 500
Qld	31	225	1 650
Qld	22	911	1 650
NSW	31	170	2 000
Vic.	31	107	2 150
WA	21	49	2 000
NSW	22	2 455	2 000
SA	22	6 5	2 150
Vic.	22	627	2 150
WA	31	159	2 500
Qld	32	1 105	2 500
WA	22	536	2 500
SA	32	3	3 000
WA	32	167	3 000
NSW	32	2 052	3 000
Vic.	32	255	3 000
Total		9 625	

a. The land is arranged in ascending order of cost per tonne of carbon sequestered, from the lowest to the highest.

b. The first digit represents plantation capability (2 = medium, 3 = high) and the second digit represents agricultural intensity (1 = low, 2 = medium).

Source BTCE estimates based on data from various sources, including unpublished CSIRO data on land suitability provided under contract to the BTCE.

RESULTS

Land required to absorb transport emissions

Costs were calculated on the basis of land and trees required to absorb varying proportions of total basecase transport emissions in each year, beginning with 20 per cent and proceeding in increments of 20 per cent (that is, 20, 40, 60, 80 and 100 per cent of basecase emissions). This approach permits calculation of marginal (incremental) costs at varying levels of application (intensity) of the instrument **(chapter 2)**.

Table 14.2 sets out the areas of land required to be planted in perpetuity to absorb various proportions of total domestic basecase transport emissions in each year from 1996 to 2015 (appendix III). The last row of the table represents the estimated total area of land (in thousand hectares) required to absorb the various proportions of all the transport emissions between 1996 and 2015.

There are over 9 million hectares of land available in Australia that is of medium or high suitability for tree plantations, but of low or medium suitability for agriculture. If all CO_2 produced by transport over the period 1996 to 2015 were to be fully absorbed, then just over 2 million hectares of land (less than a quarter of the available area) would be required.

Marginal costs would be likely to rise markedly as more agricultural land was switched to forest beyond 2015 (or if greenhouse gas abatement for sectors other than transport also relied on tree planting). Under the United Nations Framework Convention on Climate Change, countries such as Australia may plant trees in other countries on a cooperative basis. Agreement is yet to be reached on the extent to which such cooperative ventures may be counted towards national greenhouse reduction targets by developed countries, but the option would need to be considered in ascertaining costs of tree planting on a larger basis than that in this Report.

Costs of carbon sequestration

Costs were calculated in BTCE (1996c) for varying proportions of basecase emissions absorbed in a particular year. To ensure consistency with other measures analysed in this Report, costs have been calculated on the basis of cumulative emissions absorbed. Total, average and marginal costs of CO_2 cumulatively absorbed (from 1996) as at each of four 'snapshot' years (2000, 2005, 2010, 2015) are shown in table 14.3.

TABLE 14.2 LAND AREA REQUIRED TO ABSORB BASECASE TRANSPORT[a] EMISSIONS[b]

Year	Basecase transport emissions (million tonnes of C)[c]	Land required (thousand hectares) to absorb proportions of basecase emissions				
		20%	40%	60%	80%	100%
1996	18.66	17.58	35.15	52.73	70.31	87.89
1997	19.13	17.91	35.82	53.74	71.65	89.56
1998	19.59	18.26	36.51	54.77	73.03	91.28
1999	20.02	18.60	37.20	55.80	74.40	93.01
2000	20.40	18.95	37.90	56.85	75.80	94.75
2001	20.84	19.32	38.64	57.96	77.28	96.60
2002	21.28	19.70	39.39	59.09	78.79	98.48
2003	21.71	20.07	40.14	60.21	80.29	100.36
2004	22.14	20.43	40.86	61.29	81.72	102.15
2005	22.57	20.83	41.65	62.48	83.30	104.13
2006	23.00	21.23	42.47	63.70	84.94	106.17
2007	23.38	21.65	43.30	64.95	86.60	108.25
2008	23.75	22.07	44.14	66.22	88.29	110.36
2009	24.10	22.48	44.96	67.44	89.93	112.41
2010	24.44	22.92	45.84	68.76	91.67	114.59
2011	24.76	23.39	46.79	70.18	93.58	116.97
2012	25.08	23.86	47.73	71.59	95.46	119.32
2013	25.41	24.35	48.69	73.04	97.39	121.73
2014	25.75	24.84	49.69	74.53	99.38	124.22
2015	26.08	25.40	50.80	76.20	101.60	127.00
Total 1996–2015	452.09	423.85	847.70	1 271.54	1 695.39	2 119.24

a. Includes road, rail, air and sea (includes small marine craft) transport.

b. Emissions relate to CO_2 on a full combustion basis (see appendix IV) . In practice, fuel is not completely oxidised into CO_2, but methane (CH_4) and carbon monoxide (CO) break down on average within 11 years and 3 months, respectively, into CO_2.

c. To convert carbon to CO_2, multiply by 3.66.

Source BTCE 1996c, p. 15, table 1.

TABLE 14.3 PLANTING TREES: SOCIAL COSTS[a] OF ABSORBING CO_2, CUMULATED FROM 1996

(1) Proportion of cumulative basecase emissions	(2) Cumulative land required	(3) Cumulative CO_2 absorbed	(4) Change in cumulative CO_2 absorbed	(5) Social cost of cumulative CO_2 absorbed	(6) Change in social cost	(7) Average social cost[b]	(8) Marginal social cost[c]
(per cent)	(thousand hectares)	(million tonnes)	(million tonnes)	($ million)	($ million)	($ per tonne)	($ per tonne)
1996 to 2000							
20	91	71.6	71.6	129.1	129.1	1.80	1.80
40	183	143.2	71.6	258.2	129.1	1.80	1.80
60	274	214.7	71.5	387.3	129.1	1.80	1.81
80	365	286.3	71.6	516.7	129.4	1.80	1.81
100	456	357.9	71.6	645.5	128.8	1.80	1.80
1996 to 2005							
20	192	151.0	151.0	271.0	271.0	1.79	1.79
40	383	302.1	151.1	542.0	271.0	1.79	1.79
60	575	453.1	151.0	812.9	270.9	1.79	1.79
80	767	604.2	151.1	1 187.7	374.8	1.97	2.48
100	958	755.2	151.0	1 587.1	399.4	2.10	2.65
1996 to 2010							
20	302.0	237.9	237.9	427.0	427.0	1.79	1.79
40	604.0	475.8	237.9	854.7	427.7	1.80	1.80
60	906.0	713.7	237.9	1 479.5	624.8	2.07	2.63
80	1 208.0	951.6	237.9	2 098.6	619.1	2.21	2.60
100	1 510.0	1 189.5	237.9	2 725.1	626.5	2.29	2.63

Continued on next page

TABLE 14.3 PLANTING TREES: SOCIAL COSTS[a] OF ABSORBING CO_2 CUMULATED FROM 1996 (continued)

(1) Proportion of cumulative basecase emissions (per cent)	(2) Cumulative land required (thousand hectares)	(3) Cumulative CO_2 absorbed (million tonnes)	(4) Change in cumulative CO_2 absorbed (million tonnes)	(5) Social cost of cumulative CO_2 absorbed ($ million)	(6) Change in social cost ($ million)	(7) Average social cost[b] ($ per tonne)	(8) Marginal social cost[c] ($ per tonne)
1996 to 2015							
20	424	330.9	330.9	599.3	599.3	1.81	1.81
40	848	661.8	330.9	1 357.3	758.0	2.05	2.29
60	1 271	992.8	331.0	2 233.4	876.1	2.25	2.65
80	1 695	1 323.7	330.9	3 104.3	870.9	2.35	2.63
100	2 119	1 654.6	330.9	4 073.8	969.5	2.46	2.93

a. All costs (net of revenue from timber sales) are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. Average costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

c. Marginal costs are obtained by dividing the figures in column (6) by the corresponding figures in column (4).

Source BTCE estimates.

Figure 14.1 shows the marginal costs of carbon sequestration for the years 2000, 2005, 2010 and 2015 in 1996 dollars at a discount rate of 10 per cent. Marginal costs of sequestering different proportions of basecase CO_2 emissions were relatively insensitive to discount rates of 5 or 15 per cent, varying by less than 10 cents per tonne from the costs estimated at a 10 per cent discount rate.

Total costs of afforestation in any year include land costs because new land needs to be planted each year (and kept under forest thereafter in perpetuity) to absorb that year's transport emissions. Annual planting and maintenance costs are included, but the dominant component of total costs is land. Land is acquired each year according to a 'planting order' (table 14.1) determined by choosing the lowest cost land remaining, combined with its expected productivity.

Marginal costs rise between 2000 and 2015 because more expensive land is used for planting in later years. Overall, the marginal cost of absorbing CO_2 is relatively low. Even if all of the CO_2 emitted by the transport sector in 2015 were to be absorbed through tree planting, the marginal cost would be only of the order of $3 per tonne.

Passenger vehicles

Because the costs of the greenhouse effect are not known, it is not possible to estimate the benefits of reducing emissions. However, sequestration of all emissions provides an estimate of the 'control cost' of total avoidance of any damage. That is, if eliminating greenhouse gas emissions completely from the Australian transport sector to 2015 were to be worthwhile, the benefits of doing so would need to be worth at least $3 per tonne of CO_2.

In some countries, service stations participate in schemes where they contribute a proportion of their profits from fuel sales to community organisations that plant trees. Assuming that the average car travels 15 500 kilometres per year and has a fuel intensity of 12 litres per 100 kilometres, it is possible to estimate the number of trees required to fully offset Australian passenger vehicle emissions.

Assuming that 1200 trees are planted per hectare (N. Byatt, ACT Forests, pers. comm. 21 November 1995), to fully absorb emissions from the average car, seven trees would have to be planted for every year that the car is used. To ensure that the carbon dioxide was permanently removed from the atmosphere, each tree would need to be replaced after harvesting, thereby constantly expanding the area devoted to forests.

EQUITY ISSUES

Despite sales of timber, fuel wholesalers will be faced with residual costs which they are likely to pass on to consumers (the magnitude of this cost will depend on costs and revenues of forestry, and taxation arrangements relating to forest industries). Consumers would effectively face a 'forestry tax' akin to a monetary tax on fuel, so that fuel usage is likely to fall.

Both a monetary carbon tax and a forestry carbon tax would discourage consumers from using fossil fuels and encourage producers to find substitutes. However, the mandated growing of trees which generates the implicit forestry tax would also result in the absorption of emissions. The forestry tax would therefore be able to be lower than a carbon tax in achieving any target reduction in CO_2 emissions. The maximum estimated marginal cost per tonne of CO_2 sequestered of about $3 translates into less than 1 cent per litre of petrol or diesel.

A carbon tax and a forestry tax would both result in a deadweight loss in consumer welfare. Because its absolute level would be lower, however, the forestry tax would entail a lower deadweight loss.

Forestry plantations may also decrease soil erosion, add to recreational facilities, and increase biodiversity and water quality (although regular harvesting, and replanting of non-native species, will limit such benefits). The public-good nature of these benefits, as well as any reductions in noxious emissions or traffic congestion, will partially offset any loss in consumer surplus due to increased fuel prices.

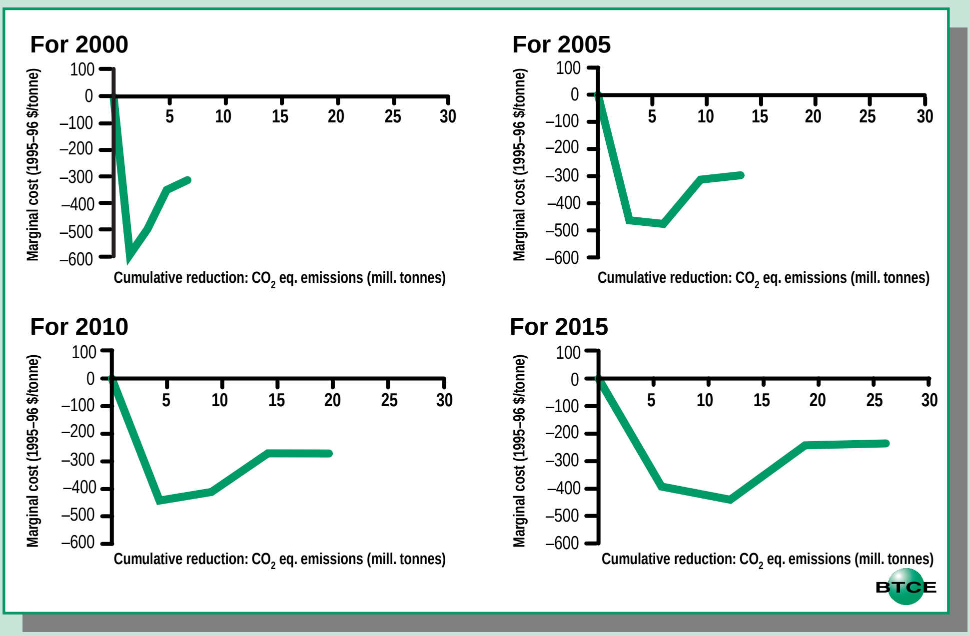
Most Australians use transport powered by fossil fuels. Revenue from a fuel or carbon tax that was returned to taxpayers in general (through compensating reductions in other tax sources or through increased government expenditure) would tend to offset the effect of the fuel or carbon tax. This 'recycling of revenue' effect does not arise for the instrument presented in this chapter because fuel wholesalers simply pass on residual costs of planting trees to their customers. Passing on residual costs involves an implicit financial transfer only from purchasers of fuel to the shareholders of wholesaling firms.

...AT A GLANCE

Reducing fares through government subsidies is one method of increasing public transport patronage in capital cities. Fare reductions are a 'no regrets' measure because social costs are negative, due primarily to reduced traffic congestion. However, only a maximum of about 26 million tonnes of CO_2 equivalent reduction in greenhouse emissions could be achieved from 1996 to 2015.

- The average number of passengers in private cars used for commuting is only 1.1 per vehicle. Increased use of urban public transport (UPT) in peak-hours would reduce use of fuel per passenger-kilometre travelled.
- Fare reductions of 20, 40, 60, and 80 per cent (through government subsidies to UPT) were evaluated as a method of reducing car travel.
- If UPT fares were reduced to 80 per cent of normal levels, commuting travel by private cars would fall by about 12 per cent. Total emissions from all passenger transport in urban areas (private car and UPT) would be about 4 per cent lower.

FIGURE 15.1 UPT FARE REDUCTIONS: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 15 CHANGES IN URBAN PUBLIC TRANSPORT FARES

Studies of public transport patronage suggest that many factors affect the decision to use public transport, including safety, reliability, frequency, fares, ease of access and egress, and journey time. In Brisbane and Adelaide relatively fast express services that improved journey times, for example, resulted in a small increase in total bus patronage (Anlezark, Crouch and Currie 1994, p. 269). Patronage of some express services in Adelaide improved by one per cent, compared with a five per cent fall in bus patronage for the city as a whole.

The ITS/BTCE model **(appendix VI)** is capable of analysing four different modes of urban public transport (bus, light rail, heavy rail, and busway). The model analyses bus and train services for Sydney, Melbourne, Adelaide, Perth and Brisbane, and bus services for Canberra. Each urban public transport (UPT) mode is described by four characteristics: fare, frequency, journey time, and access and egress time. Changing any of these characteristics could alter UPT patronage. Exploratory testing suggested that reducing fares would be the most effective method of increasing UPT patronage.

Fare reductions of 20, 40, 60 and 80 per cent from current levels were examined for peak period travel. Free travel (100 per cent fare reduction) on UPT is beyond the range of the model because it was not considered in the survey of households which provided part of the data incorporated in the model. Current average fares range between $2 and $5 per trip so an 80 per cent fare reduction will result in commuters incurring fares of under $1 per trip. Table 15.1 details average UPT fares per trip in 1996 for Australian cities. The fares are averaged across all routes and modes.

Peak period fare reductions were applied equally to the six cities modelled, to all modes currently available in each city, and to all routes. (Applying fare reductions to only one mode would lead to some switching within the UPT sector and reduce the effectiveness of the

TABLE 15.1 BASECASE AND REDUCED URBAN PUBLIC TRANSPORT FARES IN 1996

($ per trip)

Year	*Current fare*	*20*[a]	*40*[a]	*60*[a]	*80*[a]
Adelaide	3.10	2.53	1.94	1.33	0.68
Brisbane	3.50	2.88	2.21	1.51	0.77
Canberra	2.70	2.17	1.63	1.09	0.55
Melbourne	3.94	3.22	2.47	1.69	0.87
Perth	3.30	2.68	2.05	1.39	0.71
Sydney	4.57	3.67	2.77	1.86	0.93

a. Intensity levels are 20, 40, 60 and 80 per cent fare reductions.

Source BTCE estimates.

instrument in terms of commuters shifting from cars to UPT.) Fare reductions were assumed to be introduced simultaneously from 1996.

Limiting fare reductions to particular routes, such as travel to and from the central business district (CBD), would generate lower costs than for city-wide fare reductions. However, this option would considerably limit the potential reduction of greenhouse gas emissions, because less than 25 per cent of commuters in each Australian city work in the CBD.

METHODOLOGY

In practice, governments would need to set fares at specified levels and provide subsidies to operators to compensate for losses in revenue. This condition was assumed as the basis of analysis below.

Emission changes

Changes in CO_2 emissions from private transport were estimated directly from the ITS/BTCE model, where changes made by households in their travel behaviour, vehicle types and residential and workplace location are translated into changes in emissions from car travel. Non-CO_2 emissions were determined on the basis of changes in vehicle-kilometres travelled (VKT) by passenger cars **(appendix IV)**.

Public transport emissions are currently less than 5 per cent of car emissions (BTCE 1995c, p. 14). Consequently, even a substantial increase in emissions from public transport due to fare reductions would not significantly increase overall emission levels. Changes in UPT emissions were determined by adjusting the basecase emissions derived from BTCE (1995c, p. 224) by the percentage increase in the UPT task. For example, if rail patronage increases by 10 per cent, it is assumed that rail emissions would also increase by 10 per cent.

Social costs and benefits

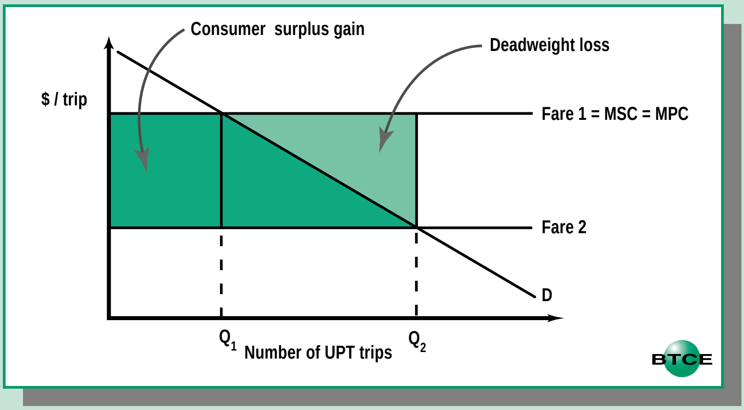
Changes in the number of UPT trips and VKT were obtained from the ITS/BTCE model. The probability of using a particular mode (for example, bus or train) is determined in the model by the cost of each mode and service characteristics such as time of journey and frequency of UPT services. Given a reduction in UPT fares, there is an increased probability of a commuter travelling on one of the available UPT modes. Demand for UPT services would therefore increase across the city. As UPT patronage increases, the demand for commuter car travel falls.

The welfare effects of a policy measure can be determined by analysing only the primary market, when there are no distortions or price changes in other markets which are affected by the policy. However, when there are distortions in other markets which are indirectly affected by the policy, overall welfare can increase or decrease. Hence, when UPT fares fall, social costs can change because of changes in the UPT market and also because of distortions in the (substitute) car travel market. The only extra cost that must be included is the loss of revenue incurred by fuel producers.

Figure 15.2 depicts the UPT market where the welfare loss is equal to the total amount paid out by the government as a subsidy on account of the fare reduction (the entire shaded area) minus the gain in consumer surplus (the darker shaded area). The loss of welfare in the UPT market is therefore equal to the area of the triangle labelled 'deadweight loss' (0.5 * ΔFare * ΔUPTtrips).

Figure 15.2 assumes that there were no existing subsidies in the UPT market, so that the initial fare level (Fare 1) equals (private and social) marginal cost. Although UPT is in reality subsidised, it is not clear how much of the subsidy should be apportioned to the peak periods, given that the high level of utilisation of services during these periods may cover their costs. BTCE (1995i, p. 23) discusses the difficulties of estimating genuine urban rail subsidies, including the problem of incorporating community service obligations such as concession fares for pensioners.

FIGURE 15.2 WELFARE CHANGE IN THE URBAN PUBLIC TRANSPORT MARKET



MSC = Marginal social cost
MPC = Marginal private cost

Note The subsidy is equal to the sum of the dark and light areas.

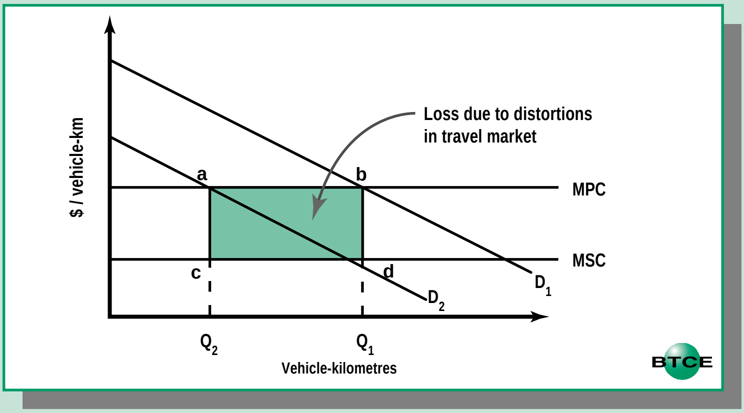
Source BTCE.

The assumption that Fare 1 equals marginal cost implies that the marginal cost of UPT provision remains constant despite an increase in the number of trips. No allowance was made for any increase in marginal costs with the provision of additional services. Low utilisation of current UPT services (BTCE & EPAV 1994, p. 20, assumes a peak loading of 56 per cent for Melbourne suburban trains) suggests that substantial capital investment is unlikely to be necessary.

Figure 15.3 represents car travel, incorporating both the number of vehicles in the passenger car fleet and distances travelled by each vehicle. A fall in the price of UPT services (figure 15.2) results in a fall in demand (represented by a shift downwards of the demand curve from D_1 to D_2 in figure 15.3) for car travel. Vehicle kilometres travelled (VKT) was chosen as the unit because it is used in the ITS/BTCE model. Using a unit different to the number of trips (appropriate for the UPT market) would not affect the results, as welfare changes are independent of the unit used to measure car travel.

Sugden and Williams (1978, pp. 135–136) show that any losses or gains experienced by commuters in one market (the car travel market, in this case) would have already been accounted for in any loss of welfare in another market (the UPT market). However, their approach does not incorporate the effects of any existing distortions in the substitute market (car travel).

FIGURE 15.3 WELFARE CHANGE IN THE CAR TRAVEL MARKET



MSC = Marginal social cost
MPC = Marginal private cost

Note Changes in the vehicle-kilometres travelled incorporate both changes in the number of vehicles in the passenger car fleet and changes in the distance travelled by each vehicle.

Source BTCE.

Distortions occur when the marginal private cost (MPC) of car travel is not equal to the marginal social cost (MSC) of car travel. The difference is usually due to taxes, subsidies, monopolies and externalities. The MPC of car travel is the generalised cost faced by commuters when making travel decisions and includes fuel, vehicle operating cost and time. The marginal social cost is the true social cost of car travel because it includes elements such as the additional cost of delay that each driver imposes on other drivers.

A fall in the demand for car travel leads to a loss of (private) consumer welfare equal to the rectangle abQ_1Q_2. Society gains the use of resources no longer used for the extra car travel, an area cdQ_1Q_2. Therefore there is a net loss to society equal to the shaded area abdc. Boadway and Wildasin (1984, pp. 391–392) discuss the theoretical basis for the welfare estimate.

Distortions in the car travel market can be divided into two groups: negative externalities (health, crash and congestion costs) and taxes (fuel excise, sales tax, parking charges, tolls and registration charges). Externalities are a cost to society but are not part of car owners' private valuation of travel and therefore are included in the MSC but not in MPC (negative externalities imply that MSC > MPC). The reverse is true for taxes: car owners have to pay the taxes, but because the revenue is simply transferred to the government, taxes are not a cost to society. Figure 15.3 shows the case when MPC > MSC, implying that taxes outweigh externalities.

Health and crash costs are determined using the methodology described in appendix X. Changes in congestion costs were estimated using the TRANSTEP model. Without prior knowledge of the results, there is no reason to expect that the cost of externalities would be less than the value of taxes.

The total welfare loss from fare reductions equals the sum of the deadweight loss triangle in figure 15.2 and the shaded rectangle abdc in figure 15.3 and loss of revenue to fuel producers (PSA 1995, p. 52 and BTCE calculations).

Costs and emissions for Australia as a whole are estimated as the sum of the costs and emissions for Sydney, Melbourne, Brisbane, Adelaide, Perth and Canberra.

RESULTS

Table 15.2 presents changes in mode choice of commuters for bus and train and for private car travel (both driving alone and ride sharing) in response to reductions in UPT fares. Results are shown only for 2015, but they do not change significantly from 1996 to 2015.

The ITS/BTCE model predicts that when fares are reduced, the majority of car commuters in all cities prefer to shift to buses rather than trains. But the change in UPT patronage differs significantly between cities. An 80 per cent fare reduction doubles bus patronage in Melbourne, but increases it by only 22 per cent in Canberra. The 80 per cent train fare reduction is most effective in Brisbane (with a 43 per cent increase in patronage) and least effective in Sydney where train patronage increases by only 14 per cent. Overall, UPT patronage increases most in Adelaide, Brisbane, Melbourne and Perth. Fare reductions have less effect in Sydney and Canberra.

Falls in VKT are made up of two components: changes in the use of the existing vehicle fleet and changes in the size of the fleet. Fleet size decreases by about 1 per cent for the 80 per cent UPT fare reduction, but VKT per vehicle falls by about 3.5 per cent. Table 15.3 shows the fall in overall VKT for each city and fare reduction level in 2015.

TABLE 15.2 CHANGE IN MODE SHARE IN 2015 DUE TO URBAN PUBLIC TRANSPORT FARE REDUCTIONS

(per cent change in mode share)

Mode	*20*[a]	*40*[a]	*60*[a]	*80*[a]
Drive alone (car)	–1.8	–3.8	–5.9	–8.2
Ride share (car)	–1.9	–4.0	–6.3	–8.7
Bus	10.4	21.9	35.0	49.6
Train	5.7	11.6	17.6	23.6

a. Intensity levels are 20, 40, 60 and 80 per cent fare reductions for urban public transport in Adelaide, Brisbane, Canberra, Melbourne, Perth and Sydney.

Source BTCE estimates.

TABLE 15.3 REDUCTION IN VEHICLE-KILOMETRES TRAVELLED DUE TO URBAN PUBLIC TRANSPORT FARE REDUCTIONS IN 2015

(per cent)

City	*20*[a]	*40*[a]	*60*[a]	*80*[a]
Adelaide	0.8	1.8	2.9	4.2
Brisbane	1.2	2.6	4.1	5.8
Canberra	0.3	0.7	1.0	1.4
Melbourne	1.2	2.6	4.1	5.8
Perth	0.6	1.2	2.0	2.8
Sydney	1.2	2.5	3.5	5.3
All cities	1.1	2.2	3.5	4.9

a. Intensity levels are 20, 40, 60 and 80 per cent fare reductions.

Source BTCE estimates.

Changes in private travel can be categorised into commuter and non-commuter travel. Applying an 80 per cent fare reduction for the six cities taken together results in a 10 per cent reduction in emissions from commuting travel, compared with about 1 per cent for non-commuting travel.

The fall in car emissions is roughly proportional to the fall of approximately 5 per cent in VKT for an 80 per cent fare reduction. Increases in UPT emissions are directly proportional to the change in UPT patronage. Despite an increase of about 34 per cent in UPT trips, emissions remain small relative to car emissions.

Table 15.4 summarises the cost effectiveness of UPT fare reductions. Marginal cost curves are shown in figure 15.1.

TABLE 15.4 URBAN PUBLIC TRANSPORT FARE REDUCTIONS: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1) Fare reduction[b]	(2) Cumulative reduction: CO_2 equivalent	(3) Change in cumulative reduction: CO_2 equivalent	(4) Social cost of cumulative reduction	(5) Change in social cost	(6) Average social cost[c]	(7) Marginal social cost[d]
(per cent)	*(million tonnes)*	*(million tonnes)*	*($ million)*	*($ million)*	*($ per tonne)*	*($ per tonne)*
1996 to 2000						
20	1.448	1.448	–862	–862	–595	–595
40	3.018	1.570	–1 645	–783	–545	–499
60	4.731	1.713	–2 246	–601	–475	–351
80	6.585	1.854	–2 828	–582	–429	–314
1996 to 2005						
20	2.884	2.884	–1 334	–1 334	–463	–463
40	6.017	3.133	–2 826	–1 492	–470	–476
60	9.428	3.411	–3 893	–1 067	–413	–313
80	13.116	3.688	–4 988	–1 095	–380	–297
1996 to 2010						
20	4.316	4.316	–1 906	–1 906	–442	–442
40	9.014	4.698	–3 835	–1 929	–425	–411
60	14.126	5.112	–5 220	–1 385	–370	–271
80	19.646	5.520	–6 718	–1 498	–342	–271
1996 to 2015						
20	5.728	5.728	–2 246	–2 246	–392	–392
40	11.971	6.243	–4 991	–2 745	–417	–440
60	18.771	6.800	–6 640	–1 649	–354	–243
80	26.113	7.342	–8 369	–1 729	–320	–235

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. Intensity levels are 20, 40, 60 and 80 per cent fare reductions.

c. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates.

A very large proportion of the negative social costs (that is, benefits) generated by UPT fare reductions is due to reduced congestion. However, the value of a reduction in congestion depends very much on the value of travel time that is assumed, and whether the same value can be applied to all reductions in travel time (see appendix XIII). Considerable caution needs to be exercised in interpreting the results in table 15.4 because the social benefits may not in fact be as great as those estimated on the basis of the $15.19 per hour used in the analysis. While it is still likely that UPT fare reductions represent a ‘no regrets’ measure, its benefits relative to other instruments are difficult to judge.

Sensitivity testing

Urban public transport services in Australia are generally subsidised by governments. However, analysis was based on the assumption that *peak* commuter services at least meet their costs. This assumption is debatable, with Brown and O’Rourke (1980, p. 368) suggesting that peak services may in fact be the most highly subsidised part of the system.

Commuters travel primarily during the peak period. Marginal costs for *peak* services are generally higher than for *off-peak* services because marginal costs must include costs of capital and maintenance of vehicles used solely in the *peak* period. Average fares may differ between commuter and non-commuter travel depending on the proportion of passengers entitled to concession fares in each period. Sensitivity testing was employed to provide an indication of the effects of existing government subsidies on the costs of the fare reduction policy.

To estimate the cost of any UPT subsidy, the BTCE examined the difference between average expenditure and average fare per trip. ACTA (1993, pp. 49–56) suggests that the difference between expenditure per trip and current fare per trip ranges between $0.39 and $7.15 depending on the mode and city considered. It is important to note that these numbers are broad estimates of the average subsidy paid for all UPT services, not commuter services in particular.

Introducing the subsidy leads to an increase in total social costs equal to the difference between current average fares and expenditure per trip multiplied by the number of additional trips caused by fare reductions. Table 15.5 shows the additional government subsidy and the resulting total costs cumulated to 2015. The existence of UPT subsidies would increase the cost of the measure, but it would also increase the costs associated with other instruments that result in increased UPT patronage, such as carbon tax. It is, therefore, unclear what effect UPT subsidies may have on the ranking of instruments.

TABLE 15.5 TOTAL COSTS OF GOVERNMENT URBAN PUBLIC TRANSPORT SUBSIDY: SENSITIVITY TESTS TO 2015

(1995–96 $ million)

Fare reduction (per cent)[a]	*Subsidy*[b]	*Total costs*
20	604	–1 642
40	1 251	–3 740
60	1 942	–4 698
80	2 678	–5 691

a. Intensity levels are 20, 40, 60 and 80 per cent fare reductions.

b. Subsidies are equal to the difference between the average expenditure and current average fare per trip.

Source BTCE estimates.

EQUITY ISSUES

Consumers gain a significant benefit from fare reductions because the cost of commuting falls substantially. Large associated falls in both crash and congestion costs also represent a benefit to society. Government would experience high costs in having to fund the fare reductions and losing tax revenue generated from car travel. Table 15.6 details the costs incurred by consumers, government and externalities.

About 90 per cent of the externalities are falls in urban congestion costs. Focusing fare reductions on commuter travel in the six major capital cities means that most of the falls in VKT occur on Australia's most congested roads, leading to very large falls in congestion costs. Although all taxpayers (rural and urban) bear the costs of a subsidy, only urban residents gain the benefits of lower fares and reduced congestion.

UPT fare reductions benefit all commuters, but are unlikely to benefit lower income households more than wealthy ones. Brown and O'Rourke (1980, p. 362) suggest that the majority of UPT users, particularly during the peak commuting period, have a reasonably high household income. The ITS/BTCE model shows that in 1993, nearly two-thirds of UPT commuter trips were undertaken by people with household incomes above $50 000 per annum.

TABLE 15.6 COMPOSITION OF TOTAL SOCIAL COSTS OF URBAN PUBLIC TRANSPORT FARE REDUCTIONS IN 2015

(1995–96 $ million)[b]

	20[a]	*40*[a]	*60*[a]	*80*[a]
Consumer	–2 000	–4 679	–8 147	–12 530
Government	2 407	5 297	8 748	12 847
Producers	13	27	42	58
Externalities	–2 871	–6 525	–9 406	–12 732
Total	–2 246	–4 991	–6640	–8 369

a. Intensity levels are 20, 40, 60 and 80 per cent fare reductions.

b. Costs are expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

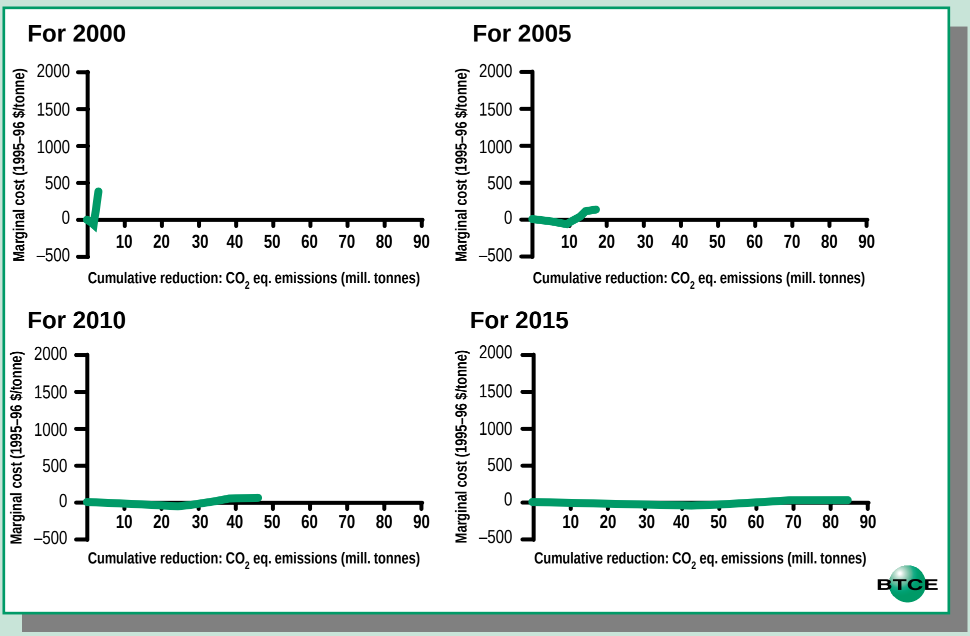
Source BTCE estimates.

...AT A GLANCE

Decreasing the roughness of roads can reduce greenhouse gas emissions without curtailing travel. An acceptable level of road roughness is 110 NRM (a measure of roughness). Resurfacing the National Highway System (NHS) to a roughness of 100 NRM (a smoother road system) would reduce road transport emissions by about 0.7 million tonnes of CO_2 equivalent by 2015 at a marginal social cost of $235 per tonne. Motorists would save about $650 million from fuel and vehicle maintenance, but government expenditure of $699 million would be required and a loss of $107 million in Commonwealth and state fuel taxes would be incurred.

- Relative to a basecase of 110 NRM, resurfacing to a roughness of 90 NRM would result in a reduction in CO_2 equivalent emissions of 1.3 million tonnes by 2015 at a marginal social cost of $716. Resurfacing to a roughness of 60 NRM would generate a reduction in emissions of 3.8 million tonnes by 2015 at a marginal social cost of about $9000 per tonne.
- Vehicle operating costs, including fuel consumption, generally decrease as road roughness decreases.
- The NHS of 18 500 kilometres links all mainland capital cities, as well as Brisbane with Cairns, and Hobart with Burnie. Cars account for 81 per cent of vehicle-kilometres travelled on the NHS, while trucks account for 19 per cent.
- Regional and rural communities would benefit because the NHS is used by people living close to highways.

FIGURE 10.1 FUEL SAVING TECHNOLOGY FOR ROAD FREIGHT VEHICLES: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 16 RESURFACING NATIONAL HIGHWAYS

The road network provides vital economic and community links across the vast expanse of the Australian continent. The 810 000 kilometres of roads range from world standard freeways to unsealed outback roads. Ninety per cent of the transport task is carried out on the major routes that comprise 20 per cent of the total road network (Austroads 1994, p. 2).

Reducing the roughness (known as 'evenness' in Europe) of heavily trafficked roads offers the potential to reduce fuel consumption, and hence greenhouse gas emissions. This analysis focuses on the National Highway System (NHS) because of the large volume of long-distance traffic that plies the NHS in relatively uncongested conditions.

National Highway System

Initially declared by the Commonwealth Government in February 1974, the NHS is a road system that links all the mainland capital cities, as well as Brisbane with Cairns, and Hobart with Burnie. As originally defined, the NHS consisted of 16 000 kilometres of road, which was extended in 1992 to about 18 500 kilometres by the inclusion of two inland freight corridors: Melbourne–Brisbane and Sydney–Adelaide. Since January 1994, links in the form of some urban extensions through Sydney, Melbourne, Brisbane, Adelaide and Perth have been included in the NHS to form a continuous network. The routes comprising the NHS are shown in figure 16.2. Table 16.1 gives the length of the NHS by state and territory.

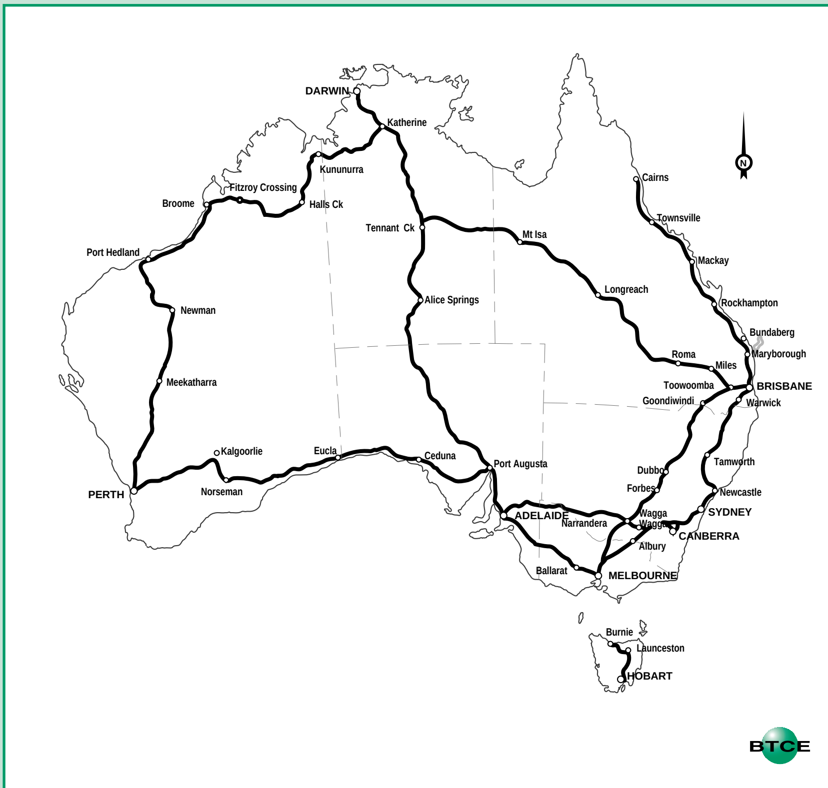
The NHS comprises twelve major routes or corridors each comprising one or more highways. Table 16.2 sets out the major routes and their highways.

TABLE 16.1 LENGTH OF NATIONAL HIGHWAY SYSTEM BY STATE AND TERRITORY

State/Territory	*Length (kilometres)*
New South Wales	3 028
Victoria	974
Queensland	4 121
Western Australia	4 634
South Australia	2 731
Tasmania	322
Northern Territory	2 670
Total	18 479

Source Austroads 1994, p. 15.

FIGURE 16.2 NATIONAL HIGHWAY SYSTEM



Source Department of Transport and Regional Development.

TABLE 16.2 MAJOR ROUTES AND HIGHWAYS COMPRISING THE NATIONAL HIGHWAY SYSTEM

Major routes	*Highways*
Sydney–Melbourne	Hume Highway
Sydney–Brisbane	Sydney–Newcastle Freeway New England Highway Cunningham Highway
Canberra connectors	Federal Highway Barton Highway
Melbourne–Adelaide	Western Highway South–Eastern Highway Dukes Highway
Sydney–Adelaide	Sturt Highway
Melbourne–Brisbane	Goulburn Valley Highway Newell Highway Gore Highway
Brisbane–Cairns	Bruce Highway
Adelaide–Perth	Adelaide–Port Augusta Road Eyre Highway Esperance–Coolgardie Highway Great Eastern Highway
Port Augusta–Darwin	Stuart Highway
Perth–Darwin	Roe Highway Great Northern Highway Victoria Highway
Brisbane–Darwin	Warrego Highway Landsborough Highway Flinders Highway (part) Barkly Highway
Hobart–Burnie	Bass Highway Midland Highway

Source DoT 1995b.

In 1992, cars accounted for 81 per cent of the 15 billion vehicle-kilometres travelled on the NHS (Austroads 1994, p. 24). Although cars contribute most of the vehicle-kilometres travelled, their share of pavement damage is negligible compared with that of trucks. The degree of pavement damage caused by a vehicle's load bearing axle increases very steeply with axle load. The degree of pavement damage has traditionally been considered to be proportional to the fourth power of the ratio of the actual axle load to the 8.2-tonne standard axle (fourth power law). (An equivalent standard axle, ESA, is defined as the effect on a pavement of a pass by a standard reference axle, which is a dual-tyred axle with a load of 8.2 tonnes.) However, the fourth power law is considered to hold only approximately, as pavement response to axle loading is complex and depends on factors such as pavement type and thickness, type of pavement distress (for example, roughness, rutting and cracking), severity of distress, and axle configuration (Hajek 1995, p. 68).

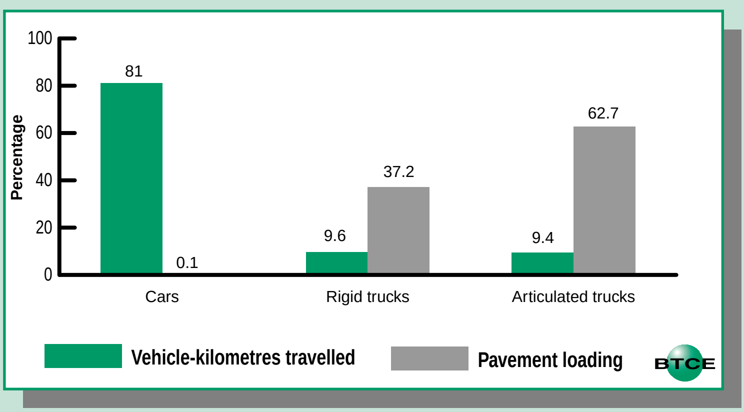
Figure 16.3 shows usage of the NHS in 1992 in terms of vehicle-kilometres travelled and the contribution to pavement loading by cars, rigid trucks and articulated trucks.

The Commonwealth Government funds the construction and maintenance of the NHS. Total expenditures on the NHS in 1993–94 and 1994–95 were $786.2 million and $816.1 million respectively (Department of Transport pers. comm. 8 July 1996). The Commonwealth Government can designate other roads of national significance as Roads of National Importance and fund them out of budgetary allocations for roads or from special appropriations.

Pavement deterioration and roughness

There are two main types of pavement: flexible and rigid. A flexible pavement is designed to deflect under traffic load and is built up from layers of gravel and/or crushed rock and topped with a bituminous surface. A rigid pavement is constructed with concrete or a material with high cement content and does not deflect appreciably under traffic flow. The NHS mainly comprises flexible pavements.

FIGURE 16.3 NATIONAL HIGHWAY USAGE IN 1992



Source Austroads 1994, p. 29.

Roughness results from the gradual deterioration of the road surface and/or the pavement structure as a whole (the following description of the process is based on that of T.C. Martin and E. Ramsay of ARRB Transport Research, pers. comm. 8 August 1996). Flexible pavement materials compact and deteriorate under repeated traffic loadings and weathering. Over time, cracks form on the pavement surface. Deterioration may be accelerated by water which, by seeping through the cracks, enters the subgrade and weakens the compacted subgrade materials. The sustained pressure exerted by the axles of heavy vehicles passing over the pavement after cracking has begun contributes to a more rapid deterioration of the road.

Increased roughness reduces surface drainage, resulting in water accumulating on the surface and affecting vehicle performance and safety. Roughness also affects the comfort of road users, the 'wear and tear' on vehicles, vehicle operating costs (VOCs) and the speed of travel.

Road condition is a multidimensional concept which includes distress (cracking, potholes etc.), rut depths, roughness, structural strength and other factors (OECD 1984, p. 61). However, road roughness is the preferred variable representing pavement performance because it is an objective measure, has a low collection cost, relates directly to road-user costs and is the most relevant measure of the long-term behaviour of pavements (Martin 1996, Executive Summary). Roughness progression also has the advantage of being a general indicator of both surface distress and pavement/subgrade stress (Roberts & Martin 1996, p. 2). Although roughness is not the only criterion for assessing the timing and maintenance needs of a pavement, for the purpose of this analysis it has been used as an indicator of the need for resurfacing.

Paterson (1987, p. 16) cites the following definition of roughness adopted by the American Society for Testing and Materials: 'the deviations of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads and drainage'. The definition implies that, on a scale of roughness, the roughness of a true planar surface would be zero.

The life of a highway section comprises a number of cycles. As pavements progressively deteriorate and become too rough, they are either reconstructed or resurfaced. When a pavement is reconstructed or resurfaced, it commences a new life cycle from which point it begins to deteriorate again. The typical 'sawtooth' cycle of deterioration with increasing roughness and rehabilitation is illustrated in figure 16.4. Resurfacing with an overlay will restore the service and roughness of the pavement to previous levels, but will have little effect on improving the structural condition of the pavement if it has substantially deteriorated. If deterioration of the subgrade has occurred, reconstruction of the pavement would be required in order to provide the same level of service and overall structural condition as in the previous cycle.

Mathematical equations set out in BTCE (1992c, p. 12) assume that VOC is related quadratically to road roughness for cars and linearly for trucks. These relationships suggest that cars are more sensitive to increased road roughness than trucks. However, the model used in this analysis regards relationships between VOC and roughness for all vehicles as approximately quadratic.

Highway infrastructure improvements generally have pervasive economy-wide effects, but direct benefits accrue mainly to road users. If highway surfaces deteriorate considerably over time due to neglect, motorists will incur higher VOCs, experience discomfort and increased travel time through reductions in speed, and be exposed to greater crash risk. They may also shift to alternative routes or transport modes. Road maintenance lowers the costs of vehicle maintenance, due to reduced wear on tyres and suspension components, and extends the service life of vehicles. Timely road maintenance can also considerably reduce overall future maintenance and rehabilitation costs.

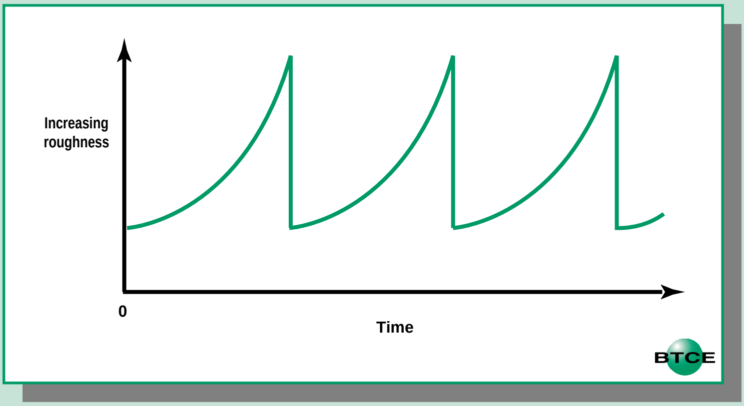
Measurement of roughness

The roughness or surface deviations of a road are random in nature, but can be characterised by a combination of waveforms of various amplitudes and wavelengths (Paterson 1987, p. 16). Roughness can be objectively measured using mechanical devices such as roadmeters and profilometers.

The international standard used to measure pavement roughness is the International Roughness Index (IRI). The IRI is based on an open-ended scale from zero for a true planar surface, increasing to about 6 for moderately rough paved roads, 12 for extremely rough paved roads with potholing and patching, and up to about 20 for extremely rough unpaved roads (Paterson 1987, p. 29). The units of IRI are dimensionless because it is a slope statistic. (IRI is generally scaled by a factor of 1000 so that it is expressed in units such as metres of roughness per kilometre or millimetres of roughness per metre.)

In Australia, roughness is generally recorded in terms of NAASRA roughness meter (NRM) counts. On major Australian roads, a roughness

FIGURE 16.4 PAVEMENT LIFE CYCLES



Source BTCE.

greater than 110 NRM is considered undesirable, and a roughness greater than 140 NRM is considered unacceptable (VIC ROADS 1992, p. 6).

Prem (1989, p. 22) sets out numerical relationships between NRM and IRI.

METHODOLOGY

The BTCE has developed a Road Infrastructure Assessment Model (RIAM) which, among other things, evaluates the impact of roughness on VOC. A number of algorithms are available for representing road deterioration. RIAM uses Paterson's algorithm developed for the World Bank (Paterson 1987, p. 304).

The generalised form of Paterson's equation for roughness as a function of time and ESAs is:

$$R(\mathrm{t}) = \left[R_0 + k(1+\mathrm{SNC})^{-4.99} Y(\mathrm{t})\right] e^{mt}$$

where:

t = time in years since the last resurfacing;

$R(\mathrm{t})$ = roughness at time t measured in international roughness index (IRI) units;

R_0 = roughness at time zero;

k = a constant reflecting the effect of traffic on the pavement;

SNC= modified structural number. The structural number (SN) describes the structural capacity of a pavement in terms of its ability to sustain traffic (measured in cumulative ESAs) using a single number, irrespective of the nature of the construction of the pavement. The modified structural number (SNC) is similar to SN, but includes an allowance for the contribution of the subgrade to the strength of the pavement;

Y(t) = millions of cumulative equivalent standard axles (ESAs) per lane from time zero to time t per lane;

m = a constant reflecting the effect of time and weathering on the pavement.

RIAM assumes that each commercial vehicle accounts for 2.5 ESAs while cars do not contribute any ESAs.

The relative effects of traffic and weathering depend on the relative sizes of k and m and on the modified structural number. Paterson (1987, p. 316) sets out recommended values of m depending on the climate. The value of m used in RIAM was 0.016, which is appropriate for tropical, non-freezing temperatures with a subhumid moisture environment. The value of k used was 134 (Paterson 1987, p. 297). RIAM uses modified structural numbers from a regression equation derived in BTCE (1990b, p. 28) relating structural number to the traffic for which the road is designed.

For the purpose of this analysis it has been assumed that the state of the pavement should not deteriorate beyond a minimum standard (expressed as a critical or terminal pavement roughness) the attainment of which would be a trigger for rehabilitation work to be initiated. It has been assumed that a section of a highway would be resurfaced when its (terminal) roughness reaches 110 NRM (regarded as the 'basecase' for resurfacing).

For the purpose of analysis, traffic growth estimates were expressed in terms of average annual daily traffic (AADT). Heavy vehicle travel on the NHS was assumed to grow at a uniform rate of 3 per cent per year (NTPT 1995, p. 14), while car travel growth estimates varied for different sections of the NHS (Travers Morgan pers. comm. 1994). These traffic growth estimates were applied over the period 1996–2015. RIAM uses the roughness of sections of the NHS in 1996 (drawn from the BTCE highways database) and corresponding AADT values to estimate when the last resurfacing was carried out and to predict roughness over the period 1996–2015.

After a highway has been resurfaced, RIAM assumes that the initial roughness is 50 NRM. If the current roughness is less than or equal to the assumed initial value of 50 NRM, RIAM assumes that the pavement is new. If the current value is below 50 NRM, RIAM sets the current value equal to 50 NRM, whereas if the current value exceeds 50 NRM, RIAM assumes that the pavement is old. For an old pavement RIAM progressively checks resurfacing dates back in time until it finds the date most consistent with the current roughness level. RIAM is then able to project roughness levels forward, one year at a time, for the period 1996–2015.

The NHS varies widely in terms of initial and terminal roughness levels. The values used in this analysis for initial roughness (50 NRM) and terminal roughness (110 NRM) are average representative values. In order that the change in emissions due to road surface improvements could be calculated, characteristics of the NHS other than terminal roughness (such as overall length, number of lanes and lane width, alignments, gradients, and number of bypasses) were held constant over the period 1996–2015.

In order to vary the ‘intensity’ of the instrument, the terminal roughness was varied from 110 NRM down to 60 NRM in decrements of 10 NRM, and RIAM was run for each roughness. The designated roughness determines which sections of the highway would be resurfaced in any given year. For example, a section that has a roughness of 105 NRM in 1997 will not be resurfaced during that year if the designated terminal roughness is 110 NRM, but will be resurfaced if terminal roughness is 100 NRM or below. For the purpose of the analysis, highways would be resurfaced earlier and more often as terminal roughness is progressively reduced. Table 16.3 sets out the average roughness of the NHS in 2015, estimated using RIAM, for various levels of assumed terminal roughness.

Most of the information required to run RIAM was extracted from a database maintained by the BTCE which contains data for all sections of the NHS. The data included traffic counts (AADT), proportions of rigid and articulated trucks, highway section lengths, terrain types, current roughness, terminal roughness and standard code. The standard code indicates the width and number of lanes of the highway section (two-lane narrow, two-lane wide, four- lane divided, and six-lane divided). Costs of resurfacing used in RIAM were based on data obtained from RTA (1995).

TABLE 16.3 TERMINAL AND AVERAGE ROUGHNESS OF NATIONAL HIGHWAY SYSTEM IN 2015

(NRM)

Assumed terminal roughness	*Estimated average roughness*[a]
110	80
100	76
90	72
80	67
70	58
60	55

a. Average roughness is estimated using the BTCE Road Infrastructure Assessment Model (RIAM).

Source BTCE.

RIAM incorporates a version of the World Bank's Highway Development and Maintenance (HDM) model which has been modified by the BTCE (the BTCE version is known as HDM-C, 'C' denoting congestion). The BTCE modification enables the effects of congestion to be taken into account in estimating VOC. HDM-C has been previously used by the BTCE (1994c) to assess the adequacy of intercity road infrastructure.

The generic HDM model was developed as a result of an international collaborative study (initiated by the World Bank), which involved data collection and research in several countries. Key physical and economic relationships relating to roads, particularly road deterioration, maintenance effects and road-user costs, were evaluated and quantified during the study. These empirical relationships have been incorporated into the HDM model making it possible to relate VOCs to road roughness. The BTCE's HDM-C also incorporates a capacity–congestion module, which includes an hourly vehicle volume profile over an entire year, and adjusts speeds to allow for congestion.

The roughness levels predicted by the roughness component of RIAM were processed by the HDM-C component, providing estimates of VOCs for cars, rigid trucks and articulated trucks. The VOCs are estimated for items such as fuel consumption, lubricant consumption, tyre wear and maintenance.

The free speed on an uncongested highway was held constant at 100 kilometres per hour for all levels of roughness. An improved road surface would encourage vehicles to travel at higher speeds, thereby increasing fuel consumption. However, travel on national highways is usually at or around legal speed limits. By holding uncongested highway speed constant, the analysis was able to isolate fuel consumption benefits of improving road roughness.

HDM-C was run with existing pavement roughness obtained from the database (assuming a terminal roughness of 110 NRM as the basecase) and for levels of terminal roughness representing the 'intensity' at which the road resurfacing policy may be implemented. HDM-C first estimates the amount of fuel saved due to the change in roughness and then estimates savings in other components of VOC. The amount of emission reduction is estimated from the amount of fuel saved.

Costs associated with highway resurfacing considered in the analysis comprise costs incurred by highway users, the government sector, fuel producers, and externality costs. Costs incurred by highway users are changes in vehicle operating costs which are obtained from HDM-C. The Commonwealth Government incurs costs on account of road works and on account of reduced revenue from fuel excise (transfer payment). Highway resurfacing costs used in the analysis are set out in table 16.4. Using data from PSA (1995, p. 52) and the Australian Institute of Petroleum Ltd (pers. comm. 20 February 1996) the loss of profits by producers due to reduced fuel sales was estimated at 2 per cent of the value of the difference in retail fuel revenue due to resurfacing.

TABLE 16.4 COSTS[a] OF RESURFACING HIGHWAYS

Road type	*Fixed cost ($ per km)*	*Additional variable cost ($ per mm × km of overlay)*
Two-lane narrow	150 000	800
Two-lane wide	180 000	840
Four-lane	1 000 000	1 730
Six-lane	1 300 000	2 470

a. Costs are in 1995–96 $.

Source RTA 1995.

Externality costs comprise environmental effects of emissions, which include health losses (morbidity and mortality), soiling, corrosion, vegetation damage and impaired visibility. The estimates of environmental benefits due to reduced emissions (due to lower fuel consumption) used in this analysis are based on values extracted from the general literature (appendix X). These estimates relate mainly to health effects and should be regarded as likely order of magnitude values because uncertainties in estimation produce a range of unit costs which vary by more than a factor of 100 across the different studies. For rural areas, the only emissions with a significant environmental impact are NO_x and NMVOCs ($0.07 per kg).

The quantities of emissions reduced corresponding to each intensity of the instrument (progressively lower levels of roughness) permit estimation of a marginal cost function for highway resurfacing.

The focus of the NHS resurfacing measure is on the reduction in greenhouse gas emissions achievable by resurfacing national highways. Possible effects of resurfacing national highways which have not been taken into account in this analysis include the following:

- It is assumed that there would be no induced increase in traffic volume resulting from resurfacing and therefore no increase in congestion and noise. Savings in fuel consumed due to resurfacing would result in an increase in real income for individual motorists, some proportion of which may be translated into increased use of motor vehicles (the rebound effect). Highways are used by local and regional traffic as well as by long-distance traffic. However, because of long distances involved in each corridor, lack of alternative routes and the mix of traffic, the impact of any rebound effect is not likely to be significant over the entire NHS.
- Lower pavement roughness reduces driver fatigue, thereby also reducing crash risk. Ergonomic studies have revealed links between certain vibrations caused by the condition of the highway surface and a number of physiological disturbances such as loss of visual acuity or attention, and changes in breathing and heart activity experienced as 'car sickness' (OECD 1984, p. 60). High levels of roughness can also cause water to accumulate on the road surface, resulting in spraying and splashing that can temporarily impair the visibility of drivers.
- Deteriorating highways increase crash risk, not only by their effects on drivers, but also by reducing vehicles' skid resistance because of the accumulation of water on the surface. Pak-Poy and Kneebone

Pty Ltd (1988, pp. 44–65) review several empirical studies which show that resurfacing road pavements resulted in significant reductions in crash rates. However, very low roughness could reduce friction between tyres and the road surface, thereby increasing the propensity for skidding. Substantial reductions in roughness could also contribute to an increased crash risk by motorists tending to compensate (risk compensation and risk homeostasis) for easier and better driving conditions by behavioural adjustments such as reduced attention to the driving task, greater speeds, shorter stopping distances, and smaller gaps between vehicles (BTCE 1995h, pp. 259–263).

- Any changes in the value of time for vehicle occupants and changes in vehicle depreciation.
- Reduced damage to sensitive goods carried on smoother roads.
- The value of higher levels of driver and passenger comfort and smoothness of travel.
- In the longer term, maintenance forestalls damage to the road surface, thereby reducing the incidence of vehicle chassis and windscreen damage. However, when road rehabilitation is carried out using bitumen, the risk of occurrence of such damage rises markedly just after a road is resurfaced because of the presence of loose debris such as stone chips.
- Benefits to groups such as the construction, tourism, and retail sectors. Lower transport costs would have economy-wide effects.
- Fuel is consumed and greenhouse gas emissions are generated by plant and equipment employed in road work, as well as in the manufacture of plant, equipment and road construction materials. These emissions have not been taken into account so as to be consistent with the approach adopted for other instruments analysed in this Report. Overall amounts of fuel saved and greenhouse gas emissions reduced due to resurfacing have therefore been somewhat overestimated. However, the degree of overestimation is not considered substantial relative to the level of uncertainty inherent in the results.

RESULTS

Table 16.5 sets out cumulative reductions in emissions and associated costs (for cars, rigid trucks and articulated trucks) for four ‘snapshot’ years, 2000, 2005, 2010 and 2015, at five terminal roughness levels ranging

TABLE 16.5 RESURFACING NATIONAL HIGHWAYS: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1) Terminal roughness[b] (NRM)	*(2)* Cumulative reduction: CO_2 equivalent (million tonnes)	*(3)* Change in cumulative reduction: CO_2 equivalent (million tonnes)	*(4)* Social cost of cumulative reduction ($ million)	*(5)* Change in social cost ($ million)	*(6)* Average social cost[c] ($ per tonne)	*(7)* Marginal social cost[d] ($ per tonne)
1996 to 2000						
100	0.0824	0.0824	398	398	4 830	4 830
90	0.1745	0.0921	935	537	5 358	5 831
80	0.2651	0.0906	1 746	811	6 586	8 951
70	0.3434	0.0783	2 822	1 076	8 218	13 742
60	0.3954	0.0520	4 788	1 966	12 109	37 808
1996 to 2005						
100	0.2103	0.2103	320	320	1 522	1 522
90	0.4450	0.2347	855	535	1 921	2 280
80	0.6722	0.2272	1 712	857	2 547	3 772
70	1.1274	0.4552	3 145	1 433	2 790	3 148
60	1.3906	0.2632	7 532	4 387	5 416	16 668
1996 to 2010						
100	0.4035	0.4035	216	216	535	535
90	0.8131	0.4096	755	539	929	1 316
80	1.2319	0.4188	1 697	942	1 378	2 249
70	1.9630	0.7311	3 650	1 953	1 859	2 671
60	2.4571	0.4941	9 820	6 170	3 997	12 487
1996 to 2015						
100	0.6652	0.6652	156	156	235	235
90	1.3128	0.6476	620	464	472	716
80	2.0281	0.7153	1 686	1 066	831	1 490
70	3.0117	0.9836	4 015	2 329	1 333	2 368
60	3.7551	0.7434	10 634	6 619	2 832	8 904

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. The roughness at which resurfacing is undertaken.

c. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates.

from 100 NRM to 60 NRM. At a terminal roughness of 100 NRM, the maximum cumulative reduction in emissions would be 0.7 million tonnes by 2015, whereas at 60 NRM the achievable reduction would be 3.8 million tonnes. Marginal costs per tonne in 2015 are $235 for 100 NRM, rising steeply to about $9000 for 60 NRM.

At a more realistic terminal roughness of 90 NRM, the maximum achievable reduction by 2015 would be 1.3 million tonnes of CO_2 equivalents at a marginal cost of $716 per tonne.

Sensitivity testing

A sensitivity analysis was carried out by varying the resurfacing costs by 33 per cent above and below the values used in the analysis. The costs for the low, medium and high cost scenarios for 2015 are set out in table 16.6.

TABLE 16.6 RESURFACING NATIONAL HIGHWAYS: SENSITIVITY TESTING OF SOCIAL COSTS[a] FOR 2015 OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

Terminal roughness[b] (NRM)	*Cumulative reduction CO_2 equivalent* (million tonnes)	*Social cost of cumulative reduction Low cost scenario[c]* ($ million)	*Social cost of cumulative reduction Medium cost scenario[d]* ($ million)	*Social cost of cumulative reduction High cost scenario[e]* ($ million)
100	0.67	–77	156	390
90	1.31	81	620	1 159
80	2.03	696	1 686	2 675
70	3.01	2 199	4 015	5 831
60	3.76	6 853	10 635	14 686

a. All costs are cumulated from 1996 to 2015 and expressed as net present values (1995–96 $) using a discount rate of 10 per cent. Negative costs represent social benefits.
b. The roughness at which resurfacing is undertaken.
c. Resurfacing costs are assumed to be 33 per cent less than for the medium scenario.
d. Resurfacing costs as assumed in the analysis (RTA 1995).
e. Resurfacing costs are assumed to be 33 per cent more than for the medium scenario.

Source BTCE estimates.

EQUITY ISSUES

The four major costs that have been considered in the analysis of highway resurfacing are costs incurred by road users, fuel producers, government, and externality (environmental) costs. Table 16.7 shows these cost components for 2015 at different levels of terminal roughness.

Resurfacing results in lower fuel consumption and vehicle maintenance costs by motorists. Consequently, producers, wholesalers and retailers of fuel would lose revenue. The Commonwealth Government would lose excise, and state governments would lose business franchise fees. Resurfacing at a terminal roughness of 100 NRM would result in an aggregate loss of Commonwealth and state/territory fuel excise of $107 million in 2015. The loss would rise to $379 million if resurfacing is carried out at a terminal roughness of 60 NRM.

The vehicle repair, maintenance and spare parts sectors would also lose revenue. As most travel on the NHS is already at or around the legal speed limits, resurfacing is not likely to generate any significant additional travel time savings.

TABLE 16.7 RESURFACING NATIONAL HIGHWAYS: COMPONENTS OF SOCIAL COSTS[a] FOR 2015 OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

($ million)

Cost components	*Terminal roughness[b] 100 NRM*	*Terminal roughness[b] 90 NRM*	*Terminal roughness[b] 80 NRM*	*Terminal roughness[b] 70 NRM*	*Terminal roughness[b] 60 NRM*
Road users[c]	–651	–1 200	–1 557	–1 773	–1 906
Fuel producers[d]	1.13	2.28	3.48	5.19	6.45
Government[e]	806	1 818	3 240	5 783	12 534
Externalities[f]	–0.05	–0.11	–0.16	–0.25	–0.31

a. All costs are cumulated from 1996 to 2015 and expressed as net present values (1995–96 $) using a discount rate of 10 per cent. Negative costs represent social benefits.

b. The roughness at which resurfacing is undertaken.

c. Road user savings comprise fuel and lubricant consumption, tyre wear, maintenance labour and parts and overhead.

d. Profits forgone by fuel producers due to reduced fuel sales following resurfacing.

e. Costs to government comprise losses in fuel excise and resurfacing costs.

f. Estimated externality benefits comprise the value of reductions in NO_x and NMVOCs.

Source BTCE estimates.

Highway resurfacing work generally causes some disruption to traffic. The effects include reduced speed and delays, windscreen and chassis damage, and increased crash risk due to altered road and traffic conditions and the temporary absence of lane marking. Likewise, resurfacing causes temporary inconvenience (including noise, dust and airborne particulate matter) to people living close to highways.

Resurfacing would reduce the operating costs of interstate bus operators. To the extent that operator's savings are passed on to passengers through the fare structure, less advantaged members of society who are more likely to use bus services would benefit. Tourism, and hence regional economies would also benefit.

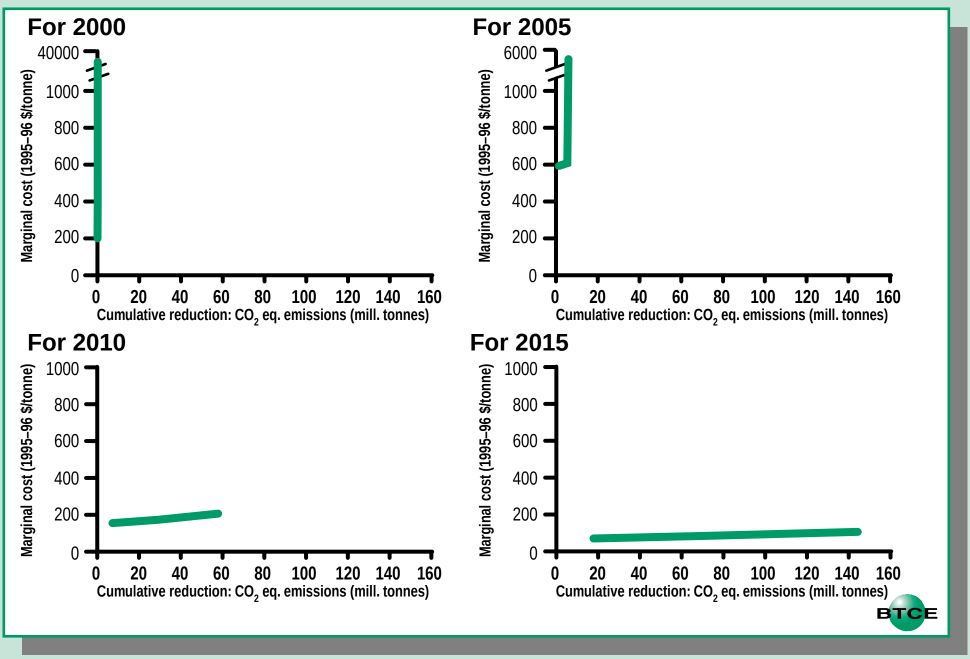
There are many towns, small population centres and farms adjacent or close to national highways. People living close to highways use them to travel to nearby towns for purposes such as obtaining services and provisions. The resurfacing of national highways would have a beneficial effect on regional mobility and welfare.

...AT A GLANCE

Alternative fuels available in the short term tend to be fossil based and offer limited reductions in greenhouse gas emissions. In the longer term, ethanol, produced on a renewable basis from trees in 'energy plantations', has the capability to replace at least 30 per cent (and possibly 60 per cent) of petrol consumption. A 60 per cent replacement of petrol by wood based ethanol by 2015 could reduce cumulative emissions between 1996 and 2015 by over 144 million tonnes of CO_2 equivalent (around 15 per cent of cumulative car emissions), but at relatively high cost.

- In the case of ethanol derived from biomass, CO_2 emitted during fuel combustion is offset by that absorbed by plants during growth. However, the use of agricultural chemicals, fuel used by farm machinery, transport of the crop, processing the crop and ethanol distillation all typically involve the use of fossil fuel based energy.
- The feedstock with the best potential to reduce overall greenhouse gas emissions is wood.
- A blend of 10 per cent ethanol and 90 per cent petrol (E10) can be used in conventional vehicles.
- An extensive program to produce ethanol from wood could increase employment opportunities in the rural sector.

FIGURE 17.1 ETHANOL MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 17 ALTERNATIVE FUELS: THE CASE OF ETHANOL

Natural gas (NG), ethanol, methanol, vegetable oils, hydrogen, electricity, liquefied petroleum gas (LPG), reformulated gasoline (petrol) and diesel are all potential alternatives to petrol. Ethanol can also be blended with petrol (commonly called gasohol) or diesel (commonly called diesohol). Methanol can also be blended with petrol.

BTCE (1994b) provides a detailed exposition of the attributes and costs of alternative transport fuels.

Diesel and LPG were the only alternative fuels in widespread use in the Australian light vehicle fleet (cars and light commercial vehicles) in 1995, accounting for about 7 and 6 per cent respectively of total light vehicle fuel use in that year **(tables II.7 and II.13)**. Petrol containing 10 per cent ethanol (E10) is available through a small number of retailers in New South Wales.

Diesel is the standard fuel used by heavy trucks (94 per cent of current consumption), with small usage of petrol, LPG and NG. Other potential alternative fuels for heavy vehicles are ethanol, diesohol and hydrogen.

Retail prices of petrol and diesel include Commonwealth Government fuel excise. At the time of writing this Report, all other alternative fuels were exempt from the fuel excise, alternative fuel vehicle conversions were exempt from sales tax, and there was a 10 per cent bounty on the production of ethanol (Nelson English, Loxton & Andrews Pty Ltd and Energy and Environmental Analysis Inc. 1996, p. 20).

Fossil based alternative fuels such as LPG are available in the near term, but can supply only a small to medium share of the market, and are of limited benefit in terms of greenhouse gas reductions. Non-fossil fuels such as ethanol from wood are likely to become available in significant quantities only in the intermediate to longer term, although they can potentially supply a large proportion of the market and offer substantial reductions in emissions. Table 17.1 summarises the possibilities.

TABLE 17.1 ALTERNATIVE FUELS AND VEHICLES

Potential market share	*Near term (non-renewable, small to medium emission reductions)*	*Intermediate and long term (renewable or ultra-low fossil fuel use, large emission reductions)*
Small to medium	CNG (16 per cent)	Methanol fuel cell (50 per cent)
	Diesel (20 per cent)	
	LPG (17 per cent)	
	M85 (3 per cent)	
	Electric (11 per cent)	
Medium to large		Ethanol from wood (70 per cent)
		Hybrid vehicles (50 per cent)[a]
		Solar hydrogen (80 per cent)
		Solar-electric (90 per cent)

CNG Compressed natural gas
LPG Liquefied petroleum gas
M85 Blend of 15 per cent petrol and 85 per cent methanol (from natural gas)

a. Hybrid vehicles are powered by an internal combustion engine (or a fuel cell) coupled to an electric drive train. The fuel is typically petrol, but can also be alternative fuels such as ethanol or hydrogen.

Note Figures in brackets refer to potential percentage reduction in CO_2 equivalent (life cycle) emissions from the use of optimised alternative vehicles, relative to basecase petrol vehicles. The percentages do not relate directly to potential reductions in total basecase emissions, which will also depend on how much of the market for road transport fuel the alternative fuel could be expected to supply (that is, the potential market share).

Sources BTCE 1994b, pp. 219, 195–196; Nelson English, Loxton & Andrews and Energy and Environmental Analysis Inc. 1996, pp. 18, 29, 31; BTCE estimates.

Production of different fuels requires differing energy inputs. Comparisons between fuels in this chapter have therefore been based on *life cycle* emissions (from energy supply, vehicle manufacture and vehicle end-use), rather than end-use emissions alone. For example, with ethanol derived from biomass, CO_2 emitted during fuel combustion is offset by that absorbed by plants during growth. However, the use of agricultural chemicals, fuel used by farm machinery, transport of the crop (or feedstock), processing the feedstock and ethanol distillation all typically involve the use of fossil fuel based energy. Although life cycle results are not strictly comparable with measures assessed in other chapters, they do offer a reasonable indication of relative costs and effectiveness.

ETHANOL

Ethanol (C_2H_5OH) can be used as a transport fuel in current vehicle types when blended with petroleum fuels or as pure alcohol in specially developed vehicles. Flexible-fuel vehicles (FFVs) capable of running on a variety of fuels (including petrol, ethanol, methanol and alcohol blends) are available and are undergoing further development internationally.

Ethanol is currently produced in Australia primarily from molasses (a by-product of the sugarcane industry) and wheat starch. Production processes based on lignocellulose from trees, as well as on sugar and starch crops, are examined in BTCE (1994b, appendix III).

Ethanol derived from food crops tends to be energy intensive, resulting in little or no greenhouse benefit over the life cycle (BTCE 1994b, pp. 62–64). Significant emission benefits are possible when the ethanol is derived from wood or waste paper. However, the lignocellulose process for producing ethanol from wood is still in the development stage, and the economic viability of mass ethanol production using this process is still to be proven.

Potential supplies of lignocellulose in Australia are large. Sufficient resources are available from field crop residues, timber harvest residues, plantation thinning, woody waste, weeds and shrubs to produce 6 billion litres of ethanol per year (equivalent to about a quarter of the energy content of current Australian petrol consumption), but at uncertain and possibly high cost (Nelson English, Loxton & Andrews Pty Ltd and Energy and Environmental Analysis Inc. 1996, p. C-4).

Feedstock yields per hectare and ease of harvesting would be considerably higher for trees planted specifically for ethanol production. Potential lignocellulose yields from tree energy plantations and forestry residues should be capable of supplying enough ethanol to replace at least 30 per cent of Australian road transport fuel consumption (BTCE 1994b, p. 54). More extensive tree planting could possibly allow an even greater share of petrol to be replaced by ethanol. Trees planted in 'energy plantations' to provide feedstock for ethanol production would need to grow for at least 10 years before initial harvesting (thinning), and would take between 20 and 35 years to reach maturity.

Planting trees on degraded or salinity affected land could help stabilise land degradation. Salt tolerant blue mallee could provide a suitable feedstock (Nelson English, Loxton & Andrews Pty Ltd and Energy and Environmental Analysis Inc. 1996, p. 56). A total substitution of petrol by

E85 (85 per cent ethanol, 15 per cent petrol) could be possible in the long term, if about 25 million hectares were committed to such tree planting, with about 4 million hectares planted by 2010 (Nelson English, pers. comm., 20 August 1996).

Replacing a significant share of petrol consumption with wood derived ethanol would involve considerable infrastructure development — Australia would need as many as 480 ethanol processing plants (with about 70 completed by 2010) to be able to make ethanol the main transport fuel in the long term (Nelson English, pers. comm., 20 August 1996). However, ethanol can be used in existing (and slightly modified) vehicles and could be supplied using the existing fuel distribution system. A variety of problems, would still have to be addressed, including possible corrosion in older vehicles and the need to reduce the water content of existing fuel pipelines.

METHODOLOGY

In order to estimate the costs associated with introducing ethanol as a major transport fuel, the following assumptions were made:

- Ethanol and petrol are taxed such that their retail prices per unit of energy are equal (that is, government, and hence taxpayers, would need to bear the cost of an implicit fuel subsidy for ethanol, since it is more costly to produce than petrol). The average cost to motorists of transport fuels has been assumed constant, because any reductions in the cost of driving will increase travel, negating the emission benefits gained by the use of the alternative fuel. The (real) retail price of petrol is assumed to remain constant at 74.2 cents per litre over the period 1996 to 2015. Fuel taxes (Commonwealth fuel excise and state business franchise fees) on petrol sales are also assumed to remain constant (in real terms) at 39.2 cents per litre (AIP 1995, pp. 19–22).
- For calculating emissions using the emission factors given in **Appendix IV**, the energy content of petrol is 34.2 megajoules per litre and of ethanol is 23.4 megajoules per litre (Bush, Holmes & Ho Trieu 1995, p. 49).
- Ethanol demand is met initially from existing production streams, with no greenhouse gas benefit obtained during the period 1996 to 2000 (Nelson English, Loxton & Andrews Pty Ltd and Energy and Environmental Analysis Inc. 1996, p. 30).

- Production of ethanol between 1996 and 2005 is assumed to remain constant at a cost of 60 cents per litre. The production cost of ethanol from sugarcane has been estimated at between 60 and 75 cents per litre, and of ethanol from starch to be about 63 cents per litre (BTCE 1994b, p. 57; Nelson English, Loxton & Andrews Pty Ltd and Energy and Environmental Analysis Inc. 1996, p. C-3).
- Distribution costs for ethanol blends are assumed to be similar to existing costs for petrol, since they would use the same distribution infrastructure. Because the water content of Australian fuel distribution systems may cause solvency difficulties with the transport of ethanol (BTCE 1994b, p. 56), some additional investment in 'drying out' existing fuel distribution could be required. It is assumed that the additional costs add 1 cent per litre to the retail price of ethanol. Nelson English, Loxton & Andrews Pty Ltd and Energy and Environmental Analysis Inc. (1996, p. C-8) estimate that the improvements required to prevent fuel tank corrosion and water contamination could add between 1 and 3 cents per litre to current fuel distribution costs. Petrol distribution costs (including retailing margins) are assumed to remain constant at 12 cents per litre. Therefore, ethanol is assumed to cost initially 73 cents per litre to produce and distribute (3.12 cents per megajoule), and to have a retail price equal on energy terms to petrol (at 2.17 cents per megajoule) requiring a subsidy of 0.95 cents per megajoule. That is, initially, ethanol sales are free from fuel excise and the production of ethanol is subsidised by around 22 cents per litre.
- FFVs and dedicated alcohol vehicles become available at a cost of $600 more than equivalent petrol vehicles (BTCE 1994b, p. 61; Nelson English, Loxton & Andrews Pty Ltd and Energy and Environmental Analysis Inc. 1996, p. 36). This cost is also assumed to be borne by the government, through sales tax subsidies to make alternative fuelled vehicles equal in retail price to petrol vehicles, in order to encourage their acceptance.
- Tree energy plantations are started in 1996, with more planted each year to 2015 (on the land and at the costs identified in **chapter 14** of this Report). Fast growing tree species are selected, such as *Pinus radiata*, giving expected yields (averaged over a 30-year harvest cycle) of around 10 tonnes of wood per hectare per annum (BTCE 1996c, pp. 33–36). The construction of infrastructure such as ethanol processing plants was also assumed to commence in 1996, to allow for a gradual introduction of ethanol produced from wood.

- E10 is assumed to be a standard fuel for petrol vehicles by 2005, but is still sourced primarily from food crops, with some production from woody wastes or forestry residues. Production from residue collection would be limited because forests tend to depend on some return of organic matter to the soil to promote the next growth cycle.
- The first tree harvest from energy plantations occurs in 2006, and consists of thinning 10 year old trees. A typical thinning program for *Pinus radiata* should yield close to 40 tonnes of wood per hectare at 10 years (BTCE 1996c, pp. 33–36). Thereafter, ethanol for transport is assumed to be sourced from the lignocellulose conversion process and to give a 68 per cent reduction in greenhouse gas emissions relative to the petrol it replaces (BTCE 1994b, p. 219).
- It is assumed that ethanol can be produced from wood by 2006 at a price of 40 cents per litre (based on BTCE 1994b, p. 58). At this production cost, ethanol would still have to be free of fuel excise. However, the subsidy required on ethanol production would decline to around 2 cents per litre.
- After 2010, advanced processes are assumed to allow the production of ethanol from wood at 20 cents per litre (BTCE 1994b, p. 58; Sinor 1996, p. 140; Nelson English, Loxton & Andrews Pty Ltd and Energy and Environmental Analysis Inc. 1996, p. C-4). At this production cost, the subsidy on ethanol production is no longer required, and ethanol sales are assumed to attract excise charges of around 18 cents per litre.

Marginal cost curves (figure 17.1) were derived using three intensity levels for the future penetration of ethanol into the car fuel market.

The first level assumes that E10 becomes the standard fuel by 2005 (that is, ethanol accounts for 10 per cent of the petrol market by 2005), and is sourced from lignocellulose from 2006 onwards. E10 can be used in conventional vehicles, so no incremental costs for new vehicle technology are required. The owners of older cars could incur some costs due to corrosion problems.

The second level assumes that E10 is used in all conventional vehicles by 2005 and that FFVs are gradually introduced, allowing ethanol to account for 30 per cent of car fuel energy consumption by 2015 (based on BTCE 1994b, p. 54), or approximately 190 petajoules per annum. This level of ethanol consumption would probably require over 30 per cent of annual new vehicle sales by 2015 to be ethanol fuelled. Between 2005 and 2015, FFVs are assumed to increase their penetration of the car fleet such that, on average, FFVs account for 1.2 per cent more of the fleet each year (based on analysis using BTCE CARMOD).

The third level assumes that E10 is used in all conventional vehicles by 2005 and that FFVs are introduced such that ethanol accounts for 60 per cent of car fuel energy consumption by 2015. Projections of likely future market shares of alternative fuels have been made by Nelson English, Loxton & Andrews Pty Ltd and Energy and Environmental Analysis Inc. (1996, p. 22–24). Their Scenario 3 (which assumes that alternative fuels are taxed so that retail prices per unit of energy are equal) forecasts a penetration of the vehicle fleet by FFVs where methanol (generated from natural gas) and ethanol (sourced from lignocellulose) each account for close to 20 per cent of the fuel market by 2010. It was assumed in this Report that this combined use of alcohol fuels could be met solely by ethanol (from wood), and that the growth trend would continue, resulting in a 60 per cent replacement of petrol by 2015.

Level 3 ethanol consumption would probably require over twice as many FFVs to be sold by 2015 as for level 2. Between 2005 and 2015, 3.2 per cent of the fleet, on average, is assumed to be replaced by FFVs each year (based on analysis using BTCE CARMOD). To obtain the 60 per cent replacement of petrol assumed for level 3 would require significant changes to existing vehicle and fuel markets, and would be an upper bound on likely ethanol penetration by 2015.

Energy plantations (using trees such as *Pinus radiata*) required to service an ethanol demand of 30 per cent of car fuel could be of the order of 4 million hectares by 2015 (based on BTCE 1994b, p. 233 and BTCE 1996c, pp. 33–51). To provide for the lower ethanol demand of level 1 (E10 replacing petrol), could require about 1 million hectares of tree energy plantations by 2015. The third level (60 per cent ethanol) would require a massive planting effort, utilising over 8 million hectares (almost all the land identified as suitable for plantations in chapter 14). Energy plantations on the land required for level 2 are assumed to allow lignocellulose feedstocks to be provided at a price of $40 per tonne by 2015.

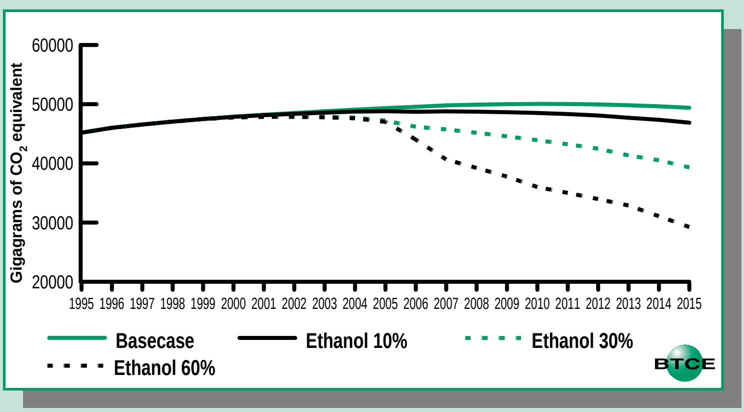
The third level requires energy plantations on more costly land, raising the price of ethanol feedstock. Based on the proportional increase in overall plantation costs, feedstock prices for a 60 per cent replacement of petrol could be around 20 per cent higher, on average, than for level 2 (30 per cent replacement). Ethanol production would cost 2 to 3 cents per litre more than for level 2. It is unknown whether level 3 would incur higher unit distribution costs (due to extra corrosion and solvency problems with high ethanol blends) or lower distribution costs (due to economics of scale). For this scenario, it was assumed the higher unit cost would be incurred and that for a 60 per cent replacement of petrol, the distribution penalty would increase from 1 cent per litre to 3 cents per litre. The retail price of ethanol for level 3 is therefore assumed to be 5 cents per litre higher than for levels 1 and 2.

The scenarios presented in this chapter require more land than the scenario in chapter 14 because no account is taken of the carbon captured below ground by forests, and because some of the land has to be cropped between 10 to 20 years after planting, well before full forest maturation (after 30 to 40 years). Also, after the trees are harvested, the carbon is not locked away for long periods in timber products (as in chapter 14), but is emitted almost immediately by vehicles consuming alcohol blend fuels.

RESULTS

The average abatement cost of reducing emissions by replacing 10 per cent of petrol use with ethanol (from tree plantations) by 2015, was estimated as $70 per tonne of CO_2 equivalent. This level of penetration of ethanol gives a 18 million tonne reduction in cumulative emissions over the period (1996–2015). A 30 per cent replacement of petrol by

FIGURE 17.2 PROJECTED GREENHOUSE GAS EMISSION LEVELS FOR BASECASE AND ETHANOL FUEL PENETRATION SCENARIOS



Source BTCE estimates.

TABLE 17.2 ETHANOL: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1) Intensity	(2) Cumulative reduction: CO_2 equivalent (million tonnes)	(3) Change in cumulative reduction: CO_2 equivalent (million tonnes)	(4) Social cost of cumulative reduction ($ million)	(5) Change in social cost ($ million)	(6) Average social cost[b] ($ per tonne)	(7) Marginal social cost[c] ($ per tonne)
1996 to 2000						
Ethanol 10%	0.0326	0.0326	233.5	233.5	7 163	7 163
Ethanol 30%	0.1303	0.0977	953.7	720.2	7 319	7 372
Ethanol 60%	0.1433	0.0130	1 439.6	485.9	10 046	37 377
1996 to 2005						
Ethanol 10%	1.3573	1.3573	804.9	804.9	593	593
Ethanol 30%	5.4326	4.0753	3 281.3	2 476.4	604	608
Ethanol 60%	5.9729	0.5403	6 359.8	3 078.5	1 065	5 698
1996 to 2010						
Ethanol 10%	7.30	7.30	1 127.9	1 127.9	155	155
Ethanol 30%	29.18	21.88	4 904.7	3 776.8	168	173
Ethanol 60%	57.89	28.71	10 826.2	5 921.5	187	206
1996 to 2015						
Ethanol 10%	17.78	17.78	1 244.2	1 244.2	70	70
Ethanol 30%	71.12	53.34	5 722.7	4 478.5	81	84
Ethanol 60%	144.31	73.19	13 475.9	7 753.2	93	106

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

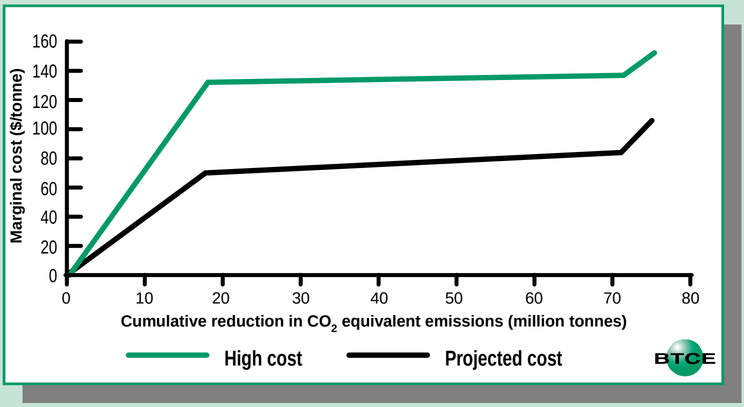
c. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates.

ethanol reduces cumulative emissions by 71 million tonnes, at an average cost of $81 per tonne, and a 60 per cent replacement reduces 144 million tonnes at $93 per tonne. The projected emission reductions are shown in figure 17.2. Marginal costs are presented in table 17.2.

If the third intensity level had been based on the projected market shares of Nelson English, Loxton & Andrews Pty Ltd and Energy and Environmental Analysis Inc. (1996, p. 22–24), that is, methanol (generated from natural gas) and ethanol (sourced from lignocellulose) accounting for roughly equal shares of the fuel market, then the average cost in 2015 would have been $130 per tonne of CO_2 equivalent emissions. The cumulative emission reduction over the period 1996–2015 would have been 75 million tonnes. The marginal cost between level 2 (30 per cent ethanol) and 30 per ethanol plus 30 per cent methanol would have been $1018 per tonne in 2015.

FIGURE 17.3 SENSITIVITY OF MARGINAL SOCIAL COSTS IN 2015 TO CHANGES IN THE PRICE OF ETHONAL



Source BTCE estimates.

TABLE 17.3 SENSITIVITY TO DISCOUNT RATES OF MARGINAL SOCIAL COSTS OF REDUCING EMISSIONS THROUGH ETHANOL FUEL USE, 2015

(1995–96 $A per tonne of cumulative CO2 equivalent emissions reduced)

	Discount rate (per cent)		
Intensity level	*5*	*10*	*15*
1	105	70	49
2	132	84	57
3	180	106	66

Source BTCE estimates.

Sensitivity testing

The results of the analysis are particularly dependent on the projected cost of large-scale production of ethanol from wood, which is currently quite uncertain.

As a sensitivity test, the results were re-estimated using a constant production cost of ethanol from wood of 60 cents per litre. This results in the average cost of ethanol replacing 30 per cent of petrol by 2105 rising to $136 per tonne of CO_2 equivalent emissions reduced. The variation to the marginal cost curve in 2015 is illustrated in figure 17.3.

Sensitivity of the results to variations in the discount rate are given in table 17.3.

EQUITY ISSUES

There are few clearly identifiable equity issues since standard petrol vehicles would be able to use E10, and would not have to be scrapped prematurely.

Because the introduction of wood based ethanol is assumed to be subsidised from government revenues (from loss in fuel excises and sales taxes on new vehicles), motorists switching to ethanol would not bear any additional (private) costs, although the community as a whole would forgo the use of any resources involved. The loss in government revenue would have to be offset by increasing other taxes or reducing government spending in other areas. For drivers of old vehicles, possible fuel system clogging and corrosion could result in additional costs (BTCE 1994b, p. 61).

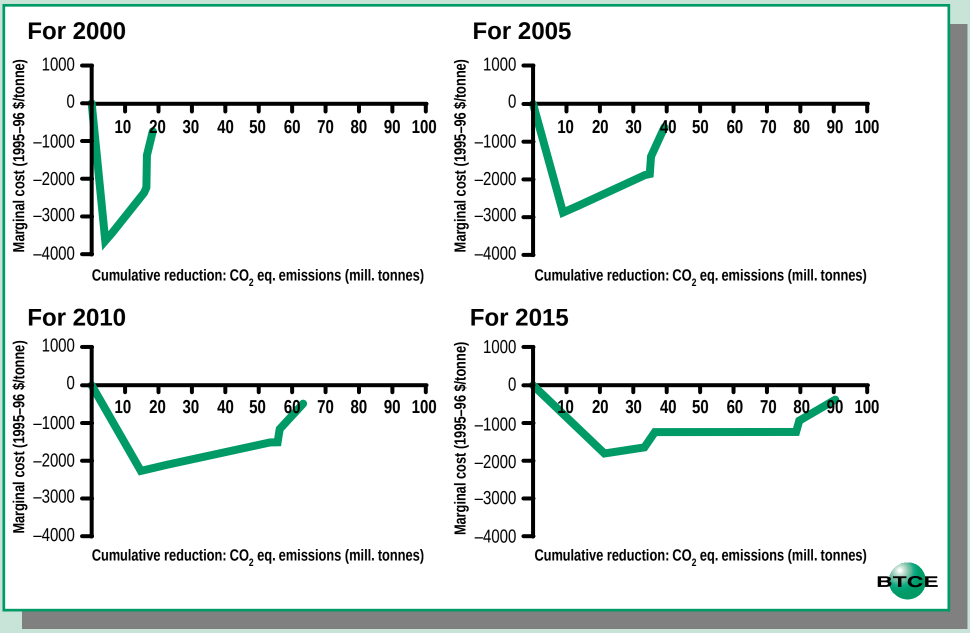
The large-scale production of ethanol using plantation wood feedstock could have significant regional impacts. The increased demand for forestry could see rural areas experience a growth in job opportunities and income levels. Increased tree planting could also benefit rural areas through reduced farmland degradation. Significant infrastructure development, such as new roads, accommodation in remote areas and ethanol processing plants, could be required in rural areas.

...AT A GLANCE

Economically efficient road user charges applied in six Australian capital cities would reduce greenhouse emissions by making motorists pay for the congestion they impose on others. They represent a clear 'no regrets' measure and would produce an overall benefit to society of about $120 billion over the period 1996 to 2015. A cumulative reduction in greenhouse gas emissions of over 90 million tonnes would also be achieved over the same period.

- It was assumed that governments impose road user charges at all urban and suburban intersections in Melbourne, Brisbane, Adelaide, Sydney, Canberra and Perth.
- Use of read-only smart cards installed in vehicles would be relatively inexpensive and would ensure protection of motorists' privacy.

FIGURE 18.1 ROAD USER CHARGES: MARGINAL SOCIAL COSTS FOR 2000, 2005, 2010 AND 2015



Source BTCE estimates.

CHAPTER 18 ROAD USER CHARGES IN CAPITAL CITIES

Road space is a scarce resource. Apart from a few new toll roads and some on-road parking, users are not charged a price for its use. Demand for the use of roads is therefore rationed only by the generalised cost of travel: vehicle operating costs and travel time. In many metropolitan areas, traffic congestion is the inevitable result.

Road users considering whether to join a congested traffic stream would normally take account of the generalised travel cost that they would expect to incur. These are the private costs against which they would weigh the benefits of travel. But road users do not take account of the fact that their decisions to travel increase congestion, and impose additional (public) costs on other road users.

Except by banning all travel, congestion cannot be entirely eliminated. However, it can be reduced to economically efficient levels by making road users take into account the costs that they impose on other road users when undertaking a trip.

A key finding of BTCE (1996d, pp. 39–43) was that a uniform congestion charge applied to a whole city or part of a city would be economically inefficient. Because uniform charges are an average, motorists would not be charged enough in highly congested areas of the city, while those travelling in less congested areas would be charged more than an economically efficient level. BTCE (1996d, table 5.3) provides details of the differences for the case of the Melbourne morning peak hour when a uniform charge is applied, compared with charges that vary with the level of congestion in different parts of the city.

BTCE (1996d) estimated economically efficient (optimal) charges that would be required on each road link for six Australian capital cities. Imposition of optimal road user charges would reduce road usage (and hence total fuel consumption by motorists) while increasing the average speed of traffic that continued to use the road network. Although some existing road users would be dissuaded from using roads (essentially suffering a loss in consumer surplus), road user charges would reduce emissions of both noxious and greenhouse gases, as well as producing a major benefit in the form of reduced travel times.

In the past, physical collection of differentiated charges in various parts of a crowded city has been considered difficult and self-defeating because of the delay that would be imposed on drivers passing toll booths. The recent development of electronic systems, however, now provides a viable method for collecting charges.

Sophisticated electronic systems could identify vehicles at various points along an urban road network, connect to a central information base or the motorist's bank account, and debit the appropriate amount for that area of the city or road.

Such systems would be expensive to install, particularly because of the substantial use of telecommunications systems. More importantly, electronic billing would provide an easily traceable record of a motorist's movements, and would therefore be likely to face substantial community opposition on privacy grounds. Although an advanced system could vary charges according to real-time congestion levels on specific sections of road, it would not necessarily be economically efficient, because drivers already in a congested area would not always be able to choose alternative, cheaper routes.

A cheaper system which would not raise privacy concerns could be based on a 'smart card' carried in the vehicle.

Smart cards could double as personal credit cards, and be capable of use as direct-debit tickets on public transport where motorists changed modes, or for on-road parking. A smart card would be debited directly as the vehicle passed through an intersection. There would be no need for recording or transfer of information to a central database on the vehicle's whereabouts or the amount charged. Credit balances for smart cards could be 'topped up' using electronic funds transfer at point of sale (EFTPOS) technology at banks, shops, or service (petrol) stations. Dashboard instrumentation could provide information and warnings on credit remaining, and roadside cameras could be used to photograph number plates of cars without valid or credit-worthy cards. Marginally increased sophistication would permit additional charging using computer monitoring of engines and exhausts for cars emitting excessive levels of noxious gases (the on-board diagnostic systems included in the analysis in chapter 4).

An adequate, practical system would require prior publication of charges for all road links in a city, prior publicity before charges were altered, dashboard display each time that charges were incurred, credit balance remaining, and so on. After an initial adjustment period, regular road users would be aware both of average costs incurred for specific trips, and the cheapest routes at various times of day.

An important consideration in any system would be the ability to use the same card on all roads in all Australian cities. Special arrangements (such as hire at outer urban petrol stations of temporary fittings for vehicles without permanent smart card equipment) would be required for non-urban motorists entering an urban road network.

METHODOLOGY

BTCE (1996d) outlines the use by the BTCE of the TRANSTEP traffic model (Nairn & Partners 1991a) to estimate economically efficient road user charges in Melbourne, Sydney, Canberra, Brisbane, Adelaide and Perth. (The results are presented as averages or totals over a grid of 3 kilometres by 3 kilometres.)

The analysis in BTCE (1996d) was based on existing levels of traffic in existing cities. However, the measures analysed in this Report are based on the period 1996 to 2015. It was therefore necessary to extend the analysis in BTCE (1996d) to take account of likely traffic growth in the six capital cities. **Appendix XIII** provides details of the method used.

Both the costs and the benefits of introducing congestion pricing were included in the estimates presented in this chapter. The costs estimated included loss of surplus suffered by road users (including road user charge payments and an uncompensated loss to those who choose not to drive because of charges), loss of fuel excise and business franchise fee revenue, the cost of fitting equipment at intersections, the cost of installed equipment to cars, and the cost of providing smart cards. The benefits estimated include travel time and fuel savings, revenues raised by road user charges (which compensate society for part of the surplus loss), and external health benefits resulting from reduction of the number of accidents and the amount of noxious emissions, which in turn result from the reduction in traffic levels.

Values of travel time in this chapter differ for each capital city, and are based on **table XIII.1** (fuel cost basis). Petrol prices used were those in **figure 8.3 (chapter 8)**.

Travel time and fuel savings, consumer and producer surplus losses, toll revenues, and decreases in travel were projected from data presented in BTCE (1996d, table 7.2), as described below.

First, an average volume of traffic was estimated for each city, with the amount of traffic from time to time (Nairn and Partners 1991b) during the day being weighted by the number of vehicle-kilometres travelled during these times. The average traffic volumes were then expressed as percentages of the traffic level in the morning peak hour. Because most travel in Sydney takes place under conditions scarcely different from those in the morning peak hour, the average conditions under which a trip is made in Sydney turned out to be about 90 per cent of peak-hour congestion. The corresponding average traffic levels as a percentage of morning peak-hour travel for the other cities estimated from travel survey data (Nairn and Partners 1991b) were approximately Adelaide 50, Brisbane 60, Canberra 50, Melbourne 60, and Perth 50.

As explained in **appendix XIII**, urban vehicle-kilometres travelled (VKT) and road network capacity were projected to the year 2015 by city, and the changing ratios between these values produced a time series, for each city, of changes in the volume–capacity ratio. The proportionate changes in volume–capacity ratios were multiplied by the current average traffic level to produce a time series, for each city, of traffic level as a proportion of the current morning peak-hour traffic. These relative volume–capacity ratios were fed into the congestion functions described in appendix XIII (which were estimated using TRANSTEP models of traffic flow with different levels of travel demand in the models of the various cities). The resulting levels of congestion cost were divided by current morning peak-hour levels to produce a time series, for each city, of the levels of congestion-related phenomena (delay, excess fuel consumption, toll revenue, etc.) as a proportion of the current peak-hour levels.

Values for travel time, excess fuel consumption, and road users' loss of surplus and revenue from charges (a transfer payment) were obtained from BTCE (1996d, table 7.2), and divided by peak-hour VKT to obtain per VKT estimates of these costs and transfers. As appropriate, the results were corrected to allow for the fact that BTCE (1996d) used a uniform $9 per person-hour value of travel time, while this chapter used values of time that varied from city to city and are provided in appendix XIII (fuel cost basis). (Road user charges, and therefore revenue, are proportional to the value of time.) To calculate the various costs and transfers in each city in each future year, the current per VKT figures were multiplied by the relative congestion factor for the relevant city in the relevant year, and the resulting future per VKT value was multiplied by VKT projected for the relevant city and year.

The percentage change in VKT that results from optimal charges was assumed to grow in the same fashion as other congestion-related values. This percentage change was projected for each city, and used to estimate a time series (for each city) of the annual VKT assuming charges were imposed. These series were compared with basecase projections to estimate travel reduction, and the health externalities of reducing accidents and noxious emissions were estimated from the VKT changes using the methods described in **appendix X**.

It was assumed that the traffic reduction caused by the imposition of the charges would result in lower average annual travel by a car fleet of the same size as the basecase fleet size. The estimates of the number of vehicles that must be provided with smart cards and in-vehicle equipment are therefore based on basecase VKT.

The cost of a new type of smart card that can be read remotely using relatively little power was assumed to be about $3 (Fox 1995). The cost of buying and installing a reader in cars to let motorists know how much they have spent at intersections as they pass through (and the credit balance remaining) was assumed to be $150 per car. Installation cost of $50 was assumed in addition to the approximate $100 cost of the unit (Fox 1995).

The costs of fitting equipment to vehicles and the costs of providing cards were estimated on the basis of a projection of the number of cars regularly used in each city. For the purposes of estimating the car fleet size in each year to 2015, it was assumed that the average distance travelled by a car on urban roads would continue at 15 000 kilometres per year. The number of cars regularly driven in each city in each year was estimated by dividing projected VKT for that city by 15 000 kilometres. On the assumption that cars will continue to be scrapped at a rate of 3 per cent per year, it was estimated that the number of new equipment fittings and cards for new cars would be equal to the increase in the car stock plus 3 per cent of the previous year's car stock. In addition, it was assumed that the smart cards would be lost or damaged at such a rate as to require replacements in each city in each year equal to 10 per cent of the stock of cards. (According to Fox 1995, the circuitry in the cards will withstand billions of read–write cycles. However, it is expected that the cards will be lost or damaged from time to time.)

The initial cost of intersection equipment was based on a recently completed feasibility study for New South Wales, which estimates costs at between $5000 and $7000 (Doug Quail, RTA, pers. comm. 29 July 1996), and the number of intersections. Annual maintenance and replacement ($60 per unit) was assumed to be approximately 1 per cent of the initial cost of the units. Costs of EFTPOS equipment in service stations was assumed to be negligible because most are already equipped with direct debit facilities, with telecommunications links to financial institutions.

The number of intersections was estimated by counting the intersections on each page in a 10 per cent random sample of the pages in the UBD street directory of Sydney (UBD 1995). The resulting average of 222 intersections per page was multiplied by the number of pages in the UBD street directories of each of the other cities, correcting where necessary for differences in map scale. The resulting estimates of the number of intersections in the various cities were as follows: Melbourne 58 835, Brisbane 20 280, Adelaide 25 629, Sydney 54 823, Canberra 21 617 and Perth 26 297. Costs of future expansion were estimated on the basis that the number of intersections would increase in proportion to projected increases in urban VKT.

As in BTCE (1996d, p. 11), only passenger travel in cars was modelled. Freight vehicles were omitted from the determination of optimal road user charges due to limitations of data and modelling. However, a fixed volume of freight traffic within each city was assumed in calibration (BTCE 1996d, pp. 45–49) of the TRANSTEP model against actual traffic volumes. An average rigid truck was assumed to be equivalent to three passenger cars while an average articulated truck was assumed equivalent to five passenger cars. The volume of freight travel was assumed to grow at a constant rate, but not in response to changes in overall congestion.

The gross capacity of road-bound public transport (mainly buses) was assumed to increase in proportion to total travel demand. Half of the increase in capacity was assumed to be expansion of the public transport system; half the increased capacity would be employed in congested areas. A bus was assumed to be equivalent to three passenger cars in estimating the contribution of buses to congestion.

As with other measures described in this report, no account was taken of the effects of any use of government revenue (a transfer payment) from the imposition of road user charges, although some of the revenue would in practice be used to maintain electronic charging systems.

RESULTS

The ‘intensities’ of application of the measure in this chapter are defined by the number of cities in which road user charges are implemented. The order of the cities is determined by the magnitude of the marginal social cost of reducing greenhouse emissions by 1 tonne in each city: implementation is assumed to start with the city with the lowest marginal cost of reducing emissions—Melbourne—progressing through the other five capital cities to Perth.

The order of marginal social costs changes over time for Sydney and Adelaide. While much greater total benefits are available from reducing congestion in Sydney, marginal benefits are higher in Adelaide in 2015 because of the pattern of congestion distribution across each city.

As travel increases in Sydney, congestion becomes spread across a wider geographical region rather than becoming more intense in congested areas. The result is to increase the area in which congested travel is taking place by roughly the same proportion as the increase in travel. Therefore the conditions under which the average kilometre is travelled become only a little more congested, and the congestion cost curve is flat **(figure XIII.1)**.

In Adelaide (like the other cities, except Brisbane), by contrast, congestion is normally confined to central areas that become more congested when the volume–capacity ratio increases. Projected increases in travel in Adelaide will thus lead to the city centre becoming rapidly more congested, moving up a steep section of the congestion cost curve. If travel demand increased enough, Adelaide would develop a saturated core like Sydney, and the congestion response curve would flatten out thereafter. The reverse (to a lesser extent) is also true, since Adelaide’s congestion cost curve is also steeper than Sydney’s at traffic levels below the peak-hour norm. Because the potential gains from reduced congestion are concentrated in a smaller area than in Sydney, slight reductions in congestion will produce greater benefits than in Sydney.

If greater marginal social benefits were desired to the year 2015 (rather than in 2000, 2005 or 2010) it would be more important to implement charges in Adelaide than Sydney. The order of the two cities in table 18.1 alternates accordingly. On the other hand, if total greenhouse gas emission reduction were the main criterion, the order of implementation would be completely different, with Sydney preceding all other cities.

TABLE 18.1 ROAD USER CHARGES: SOCIAL COSTS[a] OF REDUCTIONS IN EMISSIONS CUMULATED FROM 1996

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Intensity[b]	*Cumulative reduction: CO_2 equivalent*	*Change in cumulative reduction: CO_2 equivalent*	*Social cost of cumulative reduction*	*Change in social cost*	*Average social cost[c]*	*Marginal social cost[d]*
	(tonnes)	*(tonnes)*	*($ million)*	*($ million)*	*($ per tonne)*	*($ per tonne)*
1996 to 2000						
Melbourne	4.07	4.07	–14 826	–14 826	–3 643	–3 643
+ Brisbane	6.22	2.15	–22 200	–7 373	–3 569	–3 429
+ Sydney	15.68	9.46	–44 627	–22 427	–2 846	–2 371
+ Adelaide	16.38	0.70	–46 187	–1 560	–2 820	–2 229
+ Canberra	16.54	0.16	–46 401	–215	–2 805	–1 344
+ Perth	18.29	1.75	–47 699	–1 298	–2 597	–742
1996 to 2005						
Melbourne	8.97	8.97	–25 796	–25 796	–2 876	–2 876
+ Brisbane	13.74	4.77	–38 623	–12 827	–2 811	–2 689
+ Sydney	33.47	19.73	–75 782	–37 159	–2 264	–1 883
+ Adelaide	34.93	1.46	–78 488	–2 706	–2 247	–1 853
+ Canberra	35.30	0.37	–78 997	–509	–2 238	–1 376
+ Perth	39.31	4.01	–81 468	–2 472	–2 073	–616
1996 to 2010						
Melbourne	14.72	14.72	–33 401	–33 401	–2 269	–2 269
+ Brisbane	22.69	7.97	–50 166	–16 765	–2 211	–2 104
+ Sydney	53.37	30.68	–96 603	–46 437	–1 810	–1 514
+ Adelaide	55.64	2.27	–100 035	–3 432	–1 798	–1 512
+ Canberra	56.27	0.63	–100 765	–730	–1 791	–1 159
+ Perth	63.28	7.01	–104 170	–3 405	–1 646	–486
1996 to 2015						
Melbourne	21.36	21.36	–38 598	–38 598	–1 807	–1 807
+ Brisbane	33.31	11.95	–58 259	–19 661	–1 748	–1 645
+ Adelaide	36.44	3.13	–62 145	–3 886	–1 705	–1 242
+ Sydney	78.71	42.27	–114 383	–52 238	–1 453	–1 236
+ Canberra	79.66	0.95	–115 270	–887	–1 447	–934
+ Perth	90.44	10.78	–119 368	–4 098	–1 320	–380

a. All costs are cumulated from 1996 to each of the years shown, expressed as net present values (1995–96 $) using a discount rate of 10 per cent.

b. The 'intensity' of the road user charging scheme is varied by introducing it progressively across cities. For example, the figures in the row corresponding to + Perth relate to the effects of charging in Melbourne, Brisbane, Sydney, Adelaide, Canberra and Perth.

c. Average costs are obtained by dividing the figures in column (4) by the corresponding figures in column (2).

d. Marginal costs are obtained by dividing the figures in column (5) by the corresponding figures in column (3).

Source BTCE estimates.

The results presented in table 18.1 show that reductions in emissions of greenhouse gases can be achieved at negative marginal social cost for all six capital cities for each of the snapshot years. That is, road user charges would be socially beneficial; a clear case of a 'no regrets' measure.

Because the benefits in money terms of reducing greenhouse gas emissions are not available **(chapter 2)**, they have not been included in table 18.1. The results therefore indicate that implementation of road user charges in each of the six capital cities would be worthwhile even without taking into account the desirability of reducing greenhouse gas emissions. The benefit to the community of reduced congestion would itself outweigh the costs of implementation of a charging system.

EQUITY ISSUES

In estimating the composition of welfare effects in table 18.2, it was assumed that the government would bear the cost of installing the equipment at intersections while motorists would pay for the road user charges. Vehicle owners or vehicle manufacturers were assumed to pay for the installation of in-vehicle card readers in existing and new vehicles.

TABLE 18.2 COMPOSITION OF TOTAL SOCIAL COSTS FROM ROAD USER CHARGES IN 2015

(1995–96 $ billion)

Cities with optimal road user charges	*Private*[a]	*Government*[b]	*Externalities*[c]
Melbourne	12.6	22.4	3.6
Mel., Brisbane	20.0	32.9	5.4
Mel., Brs., Adelaide	21.3	34.6	6.2
Mel., Brs., Adl., Sydney	39.3	61.3	13.8
Mel., Brs., Adl., Syd., Canberra	39.5	61.8	14.0
Mel., Brs., Adl., Syd., Can., Perth	40.4	62.7	16.3

a. Welfare gains in the private sector come from savings in fuel and travel time. These gains are diminished by the loss of welfare from reduced travel, producer surplus loss and the cost of smart cards and in-vehicle readers, as well as the cost due to road charges.

b. Government gains are road user charge revenue minus the cost of installing equipment at intersections and losses in fuel tax revenue.

c. Externalities include benefits from lower accidents and noxious emissions. Congestion benefits are not external benefits with economically efficient road user charges.

Source BTCE estimates based on TRANSTEP model.

Unlike in the case of externalities in chapters 7 and 15 (imposing urban commuter parking charges and reducing urban public transport fares), congestion would not be considered an externality after the imposition of economically efficient road user charges. Road user charges are the market price that motorists pay for the congestion they impose on others while an externality, by definition, has no market price because there is no market for its production or consumption. Congestion reduction benefits are included in the welfare gains of the private sector.

Cities with different road networks, populations, urban densities, public transport systems and other factors will value time and reduced congestion differently **(appendix XIII)**. It follows that motorists in different cities will be affected differently by optimal road user charges. Table 18.3 shows the loss in consumer surplus per car experienced by motorists in each city in snapshot years.

Motorists would be affected differently by road user charges than by a proxy such as a petrol or carbon tax. A petrol or carbon tax has the advantage of being directed at emissions of greenhouse gases. However, a petrol tax would be relatively inefficient (that is, more expensive in terms of cost to the community as a whole) as a means of reducing congestion because many motorists travel along non-congested routes. A petrol tax would not discriminate between a motorist choosing to travel in a non-peak period or on the city's outskirts, and one who added to congestion at peak travel times in the central business district.

TABLE 18.3 ANNUAL AVERAGE CONSUMER SURPLUS LOSS PER CAR DUE TO OPTIMAL ROAD USER CHARGES

(1995–96 $)

Year	*All cities*	*Adelaide*	*Brisbane*	*Canberra*	*Melbourne*	*Perth*	*Sydney*
1996	2 080	1 298	2 519	155	765	911	4 241
2000	2 154	1 341	2 707	183	854	973	4 282
2005	2 278	1 384	2 989	219	944	1 190	4 364
2010	2 400	1 427	3 386	244	1 053	1 384	4 377
2015	2 551	1 449	3 803	275	1 132	1 618	4 466

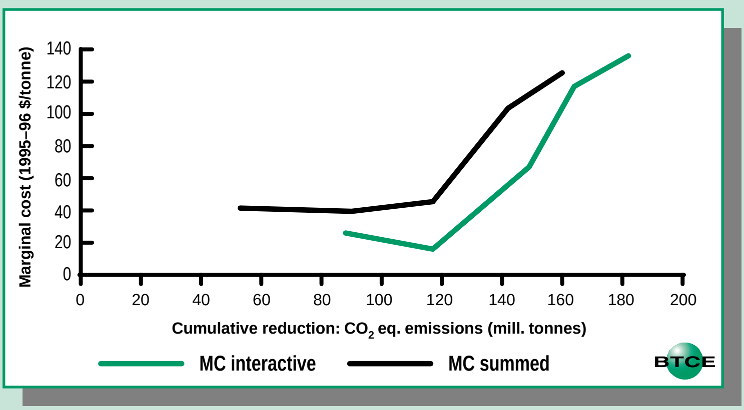
Source BTCE estimates based on TRANSTEP model.

...AT A GLANCE

Measures assessed in this Report have been analysed as if they were independent of each other. However, the overall reduction in greenhouse emissions is not necessarily a simple sum of the reductions achieved by each measure. The example presented in this chapter shows that results can differ significantly when interactions (synergies) between measures are taken into account.

- The BTCE CARMOD model was used to evaluate interactions between four measures to reduce emissions from cars. In this example, emission reductions were 13 per cent greater when the measures were interactive than if the individual emission reductions had been simply summed (figure 19.1). At the same time, combined costs of implementation were about 5 per cent lower.
- A comprehensive analysis of the interactions between all, or any combination of measures, would require development of a detailed, complex model.
- The BTCE's use of several compatible models offers a partial solution to assessing the overall effect of implementing two or more measures together.

FIGURE 19.1 MARGINAL SOCIAL COST CURVES FOR THE INTERACTIVE AND SUMMED CAR MEASURES, 2015



MC = Marginal cost

Source BTCE estimates.

CHAPTER 19 IDENTIFYING A LEAST-COST SET OF MEASURES

From the perspective of public policy, any greenhouse gas abatement measures that might be adopted by Australian governments should seek to maximise the benefits to the community. (The alternative of taking measures to adapt to any climate change with no abatement of emissions is not considered here, although an optimal response would require consideration of relative costs.)

Because the benefits of reducing levels of greenhouse gas emissions from the transport sector cannot be readily determined **(chapter 1)**, an optimal solution of maximum social benefit is also not determinable. But if policy makers wish to implement measures to reduce greenhouse gas levels by specific target amounts, then community welfare will be maximised by doing so at the lowest cost possible. That is, the most cost-effective measure or set of measures should be used.

The most cost-effective way of reducing Australia's net emissions of greenhouse gases may involve implementation of measures in any one of several sectors of the economy. Unless all possibilities are analysed, there can be no certainty that a least-cost solution has been used. However, this chapter deals only with the transport sector, for purposes of illustration of the methodology required.

STANDARD ANALYTICAL TECHNIQUES

Economics is by and large concerned with choice. Reduction of greenhouse gas emissions, for example, could be achieved in a number of different ways. The social costs of doing so would depend not only on the level of reduction, but also on the specific measures adopted.

A common technique in economic analysis is to maximise or minimise one variable subject to another. For example, costs of greenhouse abatement could be minimised subject to achieving a specified target level of emission reduction.

Baumol (1965) and Chiang (1967) provide readable expositions of standard optimisation techniques. Major techniques used in economics include the use of differential calculus to determine relative extrema, Lagrange-multiplier methods where specific constraints apply, Game theory, and linear, nonlinear and integer programming where constraints are expressed in terms of inequalities. With the increase in computing power over the last decade, techniques such as genetic algorithms are also being more widely used.

Standard optimisation techniques generally assume that the variables used are independent of each other. Estimates of costs for abatement measures presented in preceding chapters also assumed that their implementation was independent of the effects of other measures. For example, the cost-effectiveness of a carbon tax in chapter 9 was estimated as if it had no effect on, and was not affected by, a measure such as uniform urban parking charges **(chapter 7)**. This implicit assumption is valid as long as only one of the two measures is implemented, or there is no strong connection between them.

A PRACTICAL APPROACH

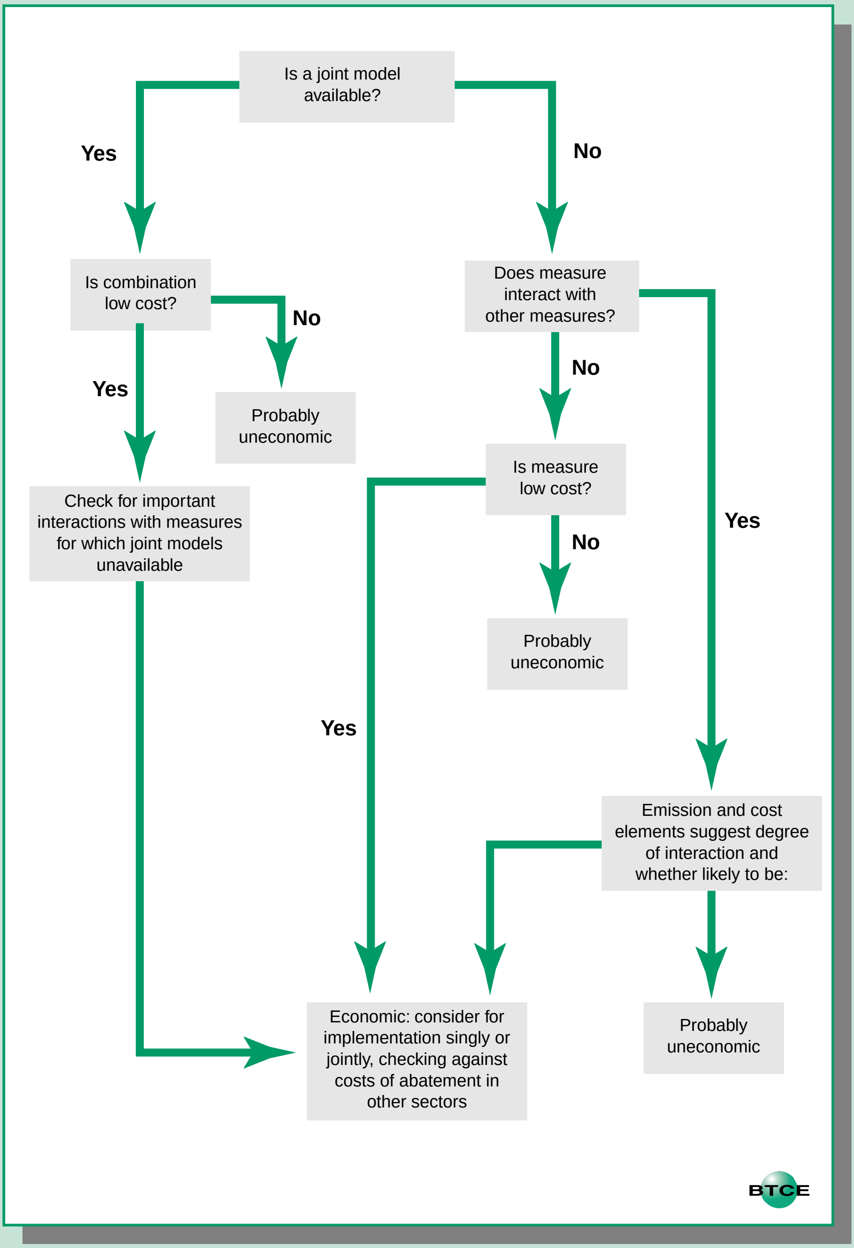
One method for dealing with the complexities of the many possible combinations of measures in the transport sector would be to construct a comprehensive interactive model. Lack of resources and data precluded full implementation of this approach.

A schematic approach to identifying a least-cost set of measures in the absence of a single, unified model is presented in figure 19.2.

Once initial assessments of interactive measures by available models has indicated the size of any gains from combinations, the remaining measures fall into two groups: those that do not interact with others to any great extent, and those that do interact (but the exact nature of the interactions cannot be incorporated into available models). The cost-effectiveness of non-interacting measures can be assessed directly. Emission and cost components of interactive measures can be examined for indications as to how their cost-effectiveness might vary if they were implemented together with other measures. Rough estimates can then be made of the effect of implementing them in combination with other measures.

The BTCE has gone part of the way towards assessing interactions among measures with the development of CARMOD and the commissioning of the ITS/BTCE model. These models can roughly simulate the interactions of a number of measures that are introduced together.

FIGURE 19.2 STYLISED APPROACH TO IDENTIFYING A LEAST-COST SET OF MEASURES FOR AUSTRALIAN TRANSPORT FROM PARTIAL EQUILIBRIUM ANALYSES



Source BTCE

AN EXAMPLE OF INTERACTIVE EFFECTS

Chapter 2 **(figure 2.5)** illustrates the effect of taking into account interdependence between different greenhouse gas abatement measures in assessing the combined effect of the measures.

To test the difference between a combined set of measures when interdependent effects are allowed for (*interactive* measures), and the same set of measures analysed on the implicit assumption of no interactions (*summed* measures), the following measures were examined (all four can be simulated separately or as an interactive combination using the BTCE CARMOD model —**appendix VII**):

- accelerated introduction of fuel saving technology in new cars;
- accelerated introduction of emission control technology in new cars;
- accelerated scrapping of high emitting cars; and
- targeted tuning of cars on the basis of roadside testing (a different measure to compulsory tuning of all passenger vehicles presented in **chapter 6**).

Interactive analysis allows for interdependencies between these measures. For example, any benefits from increased scrapping of older cars will be further enhanced if the older cars are replaced by new vehicles that are more fuel- or emissions-efficient than current models. The combined effect of accelerated introduction of technology in new cars and more stringent scrapping policies would reduce emissions multiplicatively, although the costs of implementing the measures in combination would be similar to, or even less than, the costs of introducing the two measures separately.

Roadside testing of vehicles could be used both to identify vehicles that should be scrapped and those that require tuning or catalyst replacement. Apart from reducing emissions from both perspectives, costs would be incurred jointly between the two measures.

Tables 19.1 and 19.2 provide details of the various levels of application that were used in the comparison of the 'interactive' and 'summed' measures.

For the interactive measure, the first level of application included:

- setting a standard for fuel saving technology from 1996 yielding 20 per cent of the efficiency gain assumed for the maximum technology scenario (MTS being 4 litres per 100 kilometre in 2015, see chapter 3);

TABLE 19.1 INTENSITY LEVELS FOR THE INTERACTIVE CAR MEASURE

Interactive measure intensity level	*Car technology intensity (per cent of MTS)*	*Car emissions intensity*	*Car scrapping intensity (per cent of vehicles 13 years and older)*	*Car tuning intensity (per cent of vehicles assessed as needing tuning)*	
				Pre 2000	*Post 2000*
1	20	OBD, running losses, California standards[a]	2	10	10
2	40	”	3	15	10
3	60	”	3	25	15
4	80	”	4	30	15
5	MTS	”	6	40	25

MTS Maximum technology scenario (see chapter 3)

OBD On-board diagnostics

a. Californian standards are for Ultra-low Emission Vehicle class (see chapter 4).

Source BTCE scenario analysed using the CARMOD model (appendix VII).

TABLE 19.2 INTENSITY LEVELS FOR THE SUMMED CAR MEASURE

Summed measures intensity level	*Car technology intensity (per cent of MTS)*	*Car emissions intensity*	*Car scrapping intensity (per cent of vehicles 13 years and older)*	*Car tuning intensity (tuning of cars manufactured before date)*
1	20	Catalyst replacement	1	1972
2	40	Plus OBD and running losses	2	1972
3	60	Plus California standards[a]	3	1972
4	80	Plus heated catalysts	4	1972
5	MTS	”	6	1972

MTS Maximum technology scenario (see chapter 3)

OBD On-board diagnostics

a. Californian standards are for Ultra-low Emission Vehicle class (see chapter 4).

Source BTCE scenario analysed using calculations outlined in chapters 3, 4, 5 and 6.

- use of on-board diagnostic instruments and 1999 Californian emission standards **(chapter 4)** introduced immediately;
- roadside testing was assumed to result in compulsory tuning of the worst 10 per cent of vehicles failing to meet legal emissions standards, as well as replacement of failed catalysts in all vehicles where failure is detected; and
- car scrapping was assumed to affect about 2 per cent of cars more than 13 years old each year.

Table 19.3 presents the results, for the year 2015, of analysing the four measures separately by simply adding up emission reductions and costs. It also presents the results for the same set of measures when synergies between them are taken into account. Results were not estimated for snapshot years other than 2015 because the intention was only to illustrate the interactive effects. Figure 19.1 illustrates the results given in table 19.3.

TABLE 19.3 COSTS OF INTERACTIVE AND SUMMED MEASURES, 2015

Interactive intensity	*Interactive total cost (1995–96 $ million)*	*Interactive cumulative CO_2 equivalent emission reduction (million tonnes)*	*Interactive average cost (1995–96 $/t)*	*Interactive marginal cost (1995–96 $/t)*
1	2309	88	26	26
2	2773	117	24	16
3	4916	149	33	67
4	6672	164	41	117
5	9127	182	50	136
Summed intensity	*Summed total cost (1995–96 $ million)*	*Summed cumulative CO_2 equivalent emission reduction (million tonnes)*	*Summed average cost (1995–96 $/t)*	*Summed marginal cost (1995–96 $/t)*
1	2171	53	41	41
2	3622	90	40	39
3	4859	118	41	45
4	7403	142	52	103
5	9650	160	60	125

Source BTCE estimates.

For the year 2015, emission reductions in the interactive analysis are 13 per cent larger at the maximum intensity than the simple sum of the separate measures (182 million tonnes versus 160 million tonnes). At the same time, the present value of total costs is 5 per cent lower for the interactive measure ($9650 million compared to $9127 million).

At any given level of emissions reduction, the marginal cost of the interactive measure is lower than that of the summed measure. For example, the marginal cost at the 120 million tonnes reduction level falls from $45 per tonne of cumulative CO_2 equivalent reduction for the summed analysis, to $16 per tonne in the interactive analysis. Figure 19.1 illustrates marginal costs in 2015 for the interactive measure and the sum of the measures. It can be seen that combining the measures selected into a package significantly reduces the extra cost for any given level of emissions reduction, or alternatively allows a much greater reduction in emissions for any given cost.

It should be noted that even the interactive set of measures presented in figure 19.1 may not be the most efficient one. For example, by making new cars more fuel-efficient and thus cheaper to run, the interactive measure encourages a 'rebound effect' that raises vehicle-kilometres travelled. In already congested cities, this effect generates significant costs in the model from additional congestion. It might be that the addition of a carbon tax or other demand management measure might yield an even more cost-effective result.

The principle of equi-marginality presented in **chapter 2** included the horizontal summation of marginal cost curves to produce a composite curve (**figures 2.4 and 2.5**). When interactions between cost functions are taken into account, the composite curve will not necessarily be a simple horizontal summation. Whether an interactive composite cost curve lies above and to the left, or below and to the right of its non-interactive counterpart will depend on the nature of the interactions.

Clearly, a policy that involves the implementation of more than one measure needs to take into account interactions. Otherwise, it may result in underachievement or overachievement of any targets that may have been set.

APPENDIX I THE AUSTRALIAN TRANSPORT TASK

The Australian transport task consists of a diverse range of services and activities, with greatly differing scales of operation and levels of patronage. Investigation of trends in Australian transport emission levels requires information on the underlying trends in transport task levels. Accurate estimation of transport emissions also requires detailed knowledge of the modal composition, vehicle types, vehicle utilisation levels and fuel consumption in the transport sector. This chapter provides time series estimates of aggregate transport activity for each of the main components of the Australian transport task. Time series for transport fuel consumption are given in **appendix II**.

The data presented in the following tables refer to all separate passenger and freight movements, regardless of how many modes were involved in transporting the passengers or commodities from origin to final destination. That is, transport task figures are calculated on the basis of 'unlinked' trips. Unlinked refers to the recording separately of every segment (undertaken by a distinct mode of transport) of each trip, as opposed to a 'linked' trip, which refers to a complete journey from origin to destination, possibly involving several modes. When comparing the BTCE unlinked data to any series on linked trips, note that if a multi-modal linked trip has to be assigned to a single mode, it is generally allocated to the mode for the longest segment of the journey.

Data within the Report are generally given separately for 'urban' and 'non-urban' transport. Urban transport refers to passengers or freight moved wholly within cities of population greater than 40 000 (in the relevant year). Non-urban transport refers to all other passenger or freight movements, which include those within rural areas, between different urban areas, between different rural areas and between urban and rural areas.

TABLE I.1 ESTIMATED NUMBER OF ROAD VEHICLES BY VEHICLE TYPE

(thousands of vehicles)

Year ending June	*Cars*	*Motor-cycles*	*LCVs*	*Rigid trucks*	*Articulated trucks*	*Other trucks*	*Buses*	*Total*
1971	3 997.4	164.9	611.6	286.9	32.0	10.0	17.1	5 119.9
1972	4 222.3	197.6	644.1	288.0	33.1	12.0	17.4	5 414.5
1973	4 332.2	210.4	665.1	284.3	33.6	13.8	17.8	5 557.0
1974	4 731.6	274.5	723.4	295.5	36.6	18.5	18.1	6 098.3
1975	4 983.6	289.1	773.1	302.3	39.0	24.7	18.5	6 430.3
1976	5 107.8	293.4	805.0	302.1	39.7	29.2	18.9	6 596.1
1977	5 347.1	295.0	892.7	298.6	41.8	34.1	19.6	6 928.9
1978	5 461.8	292.4	948.4	286.1	42.4	35.6	20.3	7 086.8
1979	5 652.5	288.2	1 012.3	277.7	43.9	35.5	21.1	7 331.3
1980	5 794.0	310.6	1 014.8	296.0	44.7	30.3	21.8	7 512.3
1981	6 016.0	352.3	1 044.8	319.5	45.1	23.4	22.5	7 823.5
1982	6 290.2	390.8	1 094.4	352.6	46.6	18.5	23.2	8 216.3
1983	6 479.5	401.9	1 137.4	336.8	46.2	19.2	25.6	8 446.6
1984	6 683.1	398.4	1 179.5	340.7	48.3	20.3	28.0	8 698.4
1985	6 925.9	389.2	1 221.4	341.1	49.6	21.0	30.4	8 978.7
1986	7 106.1	374.5	1 244.6	336.0	49.8	21.7	31.8	9 164.4
1987	7 227.2	351.6	1 252.3	327.1	48.2	23.2	33.2	9 262.9
1988	7 381.6	323.3	1 258.2	325.3	48.7	23.1	34.6	9 394.9
1989	7 573.7	316.6	1 291.8	329.4	50.1	19.0	36.6	9 617.1

Continued on next page

TABLE I.1 ESTIMATED NUMBER OF ROAD VEHICLES BY VEHICLE TYPE (continued)

(thousands of vehicles)

Year ending June	*Cars*	*Motor-cycles*	*LCVs*	*Rigid trucks*	*Articulated trucks*	*Other trucks*	*Buses*	*Total*
1990	7 797.3	304.0	1 316.4	329.0	51.0	16.7	37.7	9 851.9
1991	8 011.8	284.6	1 346.4	330.8	52.1	14.1	38.8	10 078.7
1992	8 143.0	292.4	1 414.1	332.4	51.7	16.3	41.4	10 291.4
1993	8 280.2	291.7	1 450.1	334.1	52.0	15.8	43.2	10 467.0

LCV Light commercial vehicle

Note Annual vehicle numbers from ABS *Motor Vehicle Registrations* data are not fully comparable over time due to changes in definition of the various vehicle types during the last 20 years. BTCE estimates have been adjusted using *Survey of Motor Vehicle Use* data on fleet characteristics to allow for inconsistencies between various years.

Sources ABS 1993a, 1993b, 1992b, 1989a, 1986b, 1983, 1981a, 1981b, 1978a, 1973; BTCE estimates based on ABS *Survey of Motor Vehicle Use* 1993a and earlier, ABS *Motor Vehicle Census* 1992b and earlier, ABS *Motor Vehicle Registrations* 1994a and earlier, CBCS 1973, p. 29, ABS 1981a, Cosgrove & Gargett 1992, and BTCE 1994a *Indicators* database.

GROWTH IN THE NUMBER OF ROAD VEHICLES

Over the last two decades the total stock of Australian road vehicles has approximately doubled, with passenger cars accounting for around 80 per cent of the fleet (table I.1). In 1993, the fleet included close to 10.5 million vehicles. Between 160 and 170 billion (10^9) kilometres are currently travelled each year by the Australian vehicle fleet, with cars accomplishing close to 80 per cent of this total (table I.2).

Comparing growth trends of the different vehicle types is complicated by discontinuities in the basic data series (annual motor vehicle registration data compiled by the Australian Bureau of Statistics [ABS]) due to changes in data coverage, methods of collection and vehicle classification. The BTCE has sought to derive consistent time series on fleet composition (given in table I.1) using published and unpublished data from the ABS *Survey of Motor Vehicle Use* (ABS 1993a and earlier). The ABS has conducted the *Survey of Motor Vehicle Use* approximately triennially over the last 20 years. Figures for years between surveys have been interpolated using annual percentage changes in the different vehicle stocks, derived from ABS (1992a) vehicle registration data.

The vehicle types most affected by revisions to the vehicle classification categories are rigid trucks and buses, and the statistics presented for these vehicle types are necessarily very approximate. Note that 'other trucks' are special purpose vehicles such as fire engines or mobile cranes, having little or no freight carrying capacity. The vehicle categories used in this Report are defined in the glossary under 'mobile sources'.

DOMESTIC FREIGHT

The movement of freight within Australia comprises a collection of activities as diverse in character as in geographical location, including the long-haul movement of domestic raw materials for secondary industry (primarily iron ore, oil and coal) by coastal sea freight, the carriage of primary products from inland mines and farms to coastal city markets and export ports by railway, and the urban and inter-city distribution of non-bulk goods by road transport.

The composition of the Australian road freight task for 1970–71 to 1992–93 is shown in table I.3. Articulated trucks perform the greatest share (83 per cent) of the non-urban road freight task (which totalled 66.6 billion tonne-kilometres in 1992–93), while the urban task (30.8 billion tonne-kilometres in 1992–93) is more evenly split between rigid and articulated trucks (with 42 and 48 per cent respectively). Light commercial vehicles account for a major part (68 per cent) of total kilometres travelled by commercial vehicles, but represent a minor component of the total road freight task in terms of tonne-kilometres (where tonne-kilometres are calculated as the product of the weight of the freight by the distance carried).

Based on *Survey of Motor Vehicle Use* data (ABS 1993a, p. 21), bulk commodities account for around 27 per cent of the total road freight task (with around 24 billion bulk tonne-kilometres out of 88.2 billion tonne-kilometres in 1990–91). Bulk freight by rail accounts for around 70 per cent of government rail freight tonne-kilometres and most of private rail freight, giving an overall bulk freight share of 80 per cent of total rail tonne-kilometres (Apelbaum 1993, pp 37–40; BTCE 1994a). Air freight is almost exclusively non-bulk and coastal sea freight is predominantly bulk (92 per cent of total tonne-kilometres).

The total domestic freight task by transport vehicles (that is, excluding pipelines) was about 289 billion tonne-kilometres for 1992–93 (table I.4), of which about 67 per cent is due to bulk commodities and 33 per cent to non-bulk. The estimates can be extended to cover freight transport by both mobile and stationary engines by including major pipeline transport (that is, pipelines involved in the transmission of fuels between points of extraction and the distribution system—data on the freight task due to the urban piped distribution of water and gas are not available). Major oil and gas pipelines account for around 6 per cent of the total domestic freight task undertaken by mobile and stationary engines (Apelbaum 1993, pp 53–60). In 1990–91, the oil pipeline network transported 18.9 Mt of oil, accounting for a task of 6.7 billion tonne-kilometres, and the natural gas (NG) pipeline network transported 12.2 Mt of gas, accounting for a task of 10.5 billion tonne-kilometres (Apelbaum 1993, p. 55). Scaling by the growth in oil and NG between 1990–91 and 1992–93 gives an estimated fuel pipeline task of 18 billion tonne-kilometres for 1992–93. The result is an estimated total domestic freight task (including pipelines) of 307 billion tonne-kilometres for 1992–93, of which 69 per cent is bulk and 31 per cent is non-bulk.

URBAN PASSENGER

Australia is highly urbanised, with ten urban localities accounting for about 70 per cent of the population (ABS 1991a). But the larger Australian cities are generally decentralised, typically evolving by the gradual extension of outer residential areas. This type of development, which frequently involves large distances between residential and work

TABLE I.2 ANNUAL VEHICLE-KILOMETRES TRAVELLED BY ROAD VEHICLE TYPE

(10^9 kilometres)

Year ending June	*Cars*	*Motor-cycles*	*LCVs*	*Rigid trucks*	*Articulated trucks*	*Other trucks*	*Buses*	*Total*
1971	63.81	1.01	9.84	4.56	1.72	0.14	0.58	81.67
1972	66.13	1.10	10.26	4.52	1.77	0.17	0.59	84.54
1973	68.06	1.20	10.81	4.51	1.79	0.20	0.61	87.18
1974	72.60	1.30	11.80	4.60	1.82	0.27	0.62	93.00
1975	76.82	1.40	12.68	4.68	1.88	0.36	0.63	98.45
1976	79.04	1.64	13.67	4.83	2.01	0.42	0.63	102.23
1977	82.71	1.68	14.94	4.71	2.15	0.44	0.64	107.28
1978	85.85	1.73	16.13	4.64	2.27	0.46	0.65	111.73
1979	87.72	1.77	17.17	4.67	2.61	0.46	0.66	115.05
1980	88.77	1.90	16.93	5.26	2.79	0.39	0.69	116.73
1981	90.28	2.00	17.44	5.83	2.80	0.30	0.73	119.39
1982	95.71	2.18	18.47	6.73	3.00	0.24	0.77	127.10
1983	96.21	2.20	18.12	6.00	2.99	0.22	0.87	126.62
1984	100.58	2.25	19.60	5.93	3.23	0.23	0.97	132.80
1985	105.67	2.28	21.63	6.10	3.59	0.24	1.07	140.58
1986	109.49	2.10	21.43	5.98	3.60	0.24	1.15	143.99
1987	112.32	2.00	21.84	6.02	3.68	0.26	1.22	147.35
1988	116.78	1.92	23.30	6.43	3.84	0.26	1.29	153.82
1989	121.70	2.00	23.62	6.46	4.06	0.27	1.35	159.46

Continued on next page

TABLE I.2 ANNUAL VEHICLE-KILOMETRES TRAVELLED BY ROAD VEHICLE TYPE (continued)

(10^9 kilometres)

Year ending June	*Cars*	*Motor-cycles*	*LCVs*	*Rigid trucks*	*Articulated trucks*	*Other trucks*	*Buses*	*Total*
1990	124.58	1.92	22.93	6.55	4.10	0.24	1.38	161.68
1991	122.57	1.61	22.81	6.11	3.96	0.20	1.36	158.62
1992	124.34	1.65	23.06	6.39	4.19	0.23	1.45	161.31
1993	126.41	1.65	24.04	6.65	4.36	0.22	1.51	164.84

LCV Light commercial vehicle

Note Utilisation estimates (vehicle-kilometres travelled) have been based on triennial ABS *Survey of Motor Vehicle Use* data, interpolated using fuel sales series (from ABARE) and vehicle population statistics (from ABS). Data on bus usage is limited, and the bus estimates are very approximate.

Sources ABS 1993a, 1993b, 1992b, 1989a, 1986b, 1983, 1981a, 1981b, 1978a, 1973; CBCS 1973; Apelbaum 1993, pp 17, 22; Cosgrove & Gargett 1992; BTCE estimates based on ABS *Survey of Motor Vehicle Use* 1993a and earlier, ABS *Motor Vehicle Census* 1992b and earlier, ABS *Motor Vehicle Registrations* 1994a and earlier, Adena & Montesin 1988, p. 140, ABARE 1991, Bush, Leonard et al. 1993, p. 112; BTCE 1994a *Indicators* database, Hensher 1989, Wilkenfeld 1991, p. 151.

TABLE I.3 AUSTRALIAN ROAD FREIGHT TASK BY VEHICLE TYPE AND AREA OF OPERATION

(10^9 tonne-kilometres)

Year ending June	*Light commercial vehicle*			*Rigid truck*			*Articulated truck*		
	Urban	*Non-urban*	*Total*	*Urban*	*Non-urban*	*Total*	*Urban*	*Non-urban*	*Total*
1971	0.75	0.62	1.37	5.41	5.21	10.62	3.00	12.20	15.20
1972	0.81	0.63	1.44	5.44	5.16	10.61	3.45	13.16	16.61
1973	0.88	0.65	1.53	5.51	5.15	10.67	3.87	13.92	17.79
1974	1.00	0.69	1.68	5.70	5.25	10.95	4.34	14.71	19.05
1975	1.11	0.72	1.82	5.89	5.33	11.22	4.94	15.80	20.75
1976	1.24	0.75	1.99	6.16	5.51	11.67	5.74	17.30	23.04
1977	1.38	0.82	2.20	6.27	5.85	12.12	6.28	18.96	25.23
1978	1.54	0.88	2.41	6.48	6.23	12.71	6.76	20.46	27.21
1979	1.67	0.93	2.60	6.85	6.80	13.64	7.90	24.00	31.90
1980	1.60	0.98	2.59	7.34	7.18	14.52	8.90	26.31	35.22
1981	1.62	1.08	2.70	7.68	7.52	15.20	9.39	27.12	36.51
1982	1.66	1.21	2.88	8.48	7.77	16.24	10.49	29.76	40.25
1983	1.65	1.21	2.86	8.19	7.37	15.55	10.67	30.69	41.36
1984	1.80	1.34	3.15	8.76	7.74	16.49	11.84	34.32	46.16
1985	2.01	1.51	3.52	9.69	8.43	18.12	13.44	39.23	52.66
1986	2.22	1.53	3.75	10.37	8.21	18.58	13.73	40.32	54.05
1987	2.51	1.61	4.12	11.35	8.12	19.46	14.34	41.83	56.17
1988	2.94	1.74	4.68	12.86	8.27	21.13	15.21	44.52	59.72
1989	2.90	1.83	4.73	12.93	8.73	21.66	15.54	48.13	63.67
1990	2.84	1.88	4.73	13.15	8.84	21.99	15.08	49.53	64.61
1991	2.86	1.89	4.75	12.16	8.39	20.55	14.01	48.90	62.91
1992	2.91	1.93	4.83	12.46	8.97	21.43	14.22	52.74	66.97
1993	3.03	2.01	5.04	12.98	9.34	22.31	14.75	55.22	69.97

Note Figures refer to unlinked freight movements. Urban figures refer to freight moved wholly within cities of population greater than 40 000. Non-urban figures refer to all other freight movements.

Sources ABS 1993a, 1993b, 1986b, 1983, 1981c, 1978a, 1973; Apelbaum 1993, p. 30; Cosgrove & Gargett 1992, p. 235; BTCE 1991a, 1991b; BTE 1980, 1975; BTCE estimates.

TABLE I.4 AUSTRALIAN DOMESTIC FREIGHT TASK (EXCLUDING PIPELINES)

(10^9 tonne-kilometres)

Year ending June	*Road*			*Rail*					
	Urban	*Non-urban*	*Total*	*Government*	*Private*	*Total*	*Sea*	*Air*	*Total*
1971	9.1	18.1	27.2	25.2	13.8	39.0	72.0	0.09	138.3
1972	9.7	19.0	28.7	25.4	16.6	42.0	83.2	0.09	154.0
1973	10.2	19.7	29.9	26.6	20.0	46.6	89.5	0.09	166.1
1974	11.0	20.7	31.7	28.3	26.5	54.8	96.1	0.11	182.7
1975	11.9	21.9	33.8	29.8	30.2	60.0	101.2	0.11	195.1
1976	13.1	23.6	36.7	30.8	26.3	57.1	104.6	0.11	198.5
1977	13.9	25.7	39.6	32.0	27.3	59.3	102.3	0.11	201.3
1978	14.7	27.6	42.3	31.5	28.4	59.9	105.1	0.11	207.5
1979	16.4	31.8	48.2	33.4	25.6	59.0	104.7	0.11	212.0
1980	17.8	34.5	52.3	35.4	27.8	63.2	105.1	0.11	220.7
1981	18.6	35.8	54.4	37.4	28.9	66.3	110.3	0.11	231.1
1982	20.6	38.8	59.4	38.0	27.4	65.4	97.8	0.12	222.7
1983	20.5	39.3	59.8	34.0	25.0	59.0	80.9	0.12	199.8
1984	22.4	43.4	65.8	40.1	23.3	63.4	94.3	0.14	223.6
1985	25.1	49.2	74.3	44.2	28.4	72.6	96.3	0.14	243.4
1986	26.3	50.1	76.4	48.2	29.2	77.4	101.8	0.14	255.7
1987	28.2	51.6	79.8	49.6	30.3	79.9	95.2	0.13	255.0
1988	31.0	54.5	85.5	50.5	31.0	81.5	93.6	0.14	260.7
1989	31.4	58.7	90.1	51.9	28.7	80.6	90.7	0.14	261.6
1990	31.1	60.3	91.4	54.4	32.5	86.9	94.2	0.08	272.6
1991	29.0	59.2	88.2	54.8	35.3	90.1	93.8	0.12	272.2
1992	29.6	63.6	93.2	56.7	35.1	91.7	96.4	0.13	281.5
1993	30.8	66.6	97.3	59.4	35.8	95.2	96.0	0.14	288.7

Note Figures refer to unlinked freight movements. Urban figures refer to freight moved wholly within cities of population greater than 40 000 in the relevant year. Non-urban figures refer to all other freight movements.

Sources Apelbaum 1993, pp 30, 37, 40, 49, 50; ABS 1993a, 1991b, 1986b, 1983, 1981a, 1981b, 1978a, 1973; CBCS 1973; BTCE 1991a, 1991b, 1989; BTE 1982a, 1980, 1975; DOTC 1991a, 1991b; Cosgrove & Gargett 1992, p. 234; BTCE 1994a Indicators database; BTCE estimates.

locations, has resulted in considerable dependence being placed on private cars for urban commuting, and correspondingly limited reliance on public transit systems. Population projections by capital city are presented in table I.5.

Table I.6 presents estimates for urban motorised travel (from 1970–71 to 1992–93), in which the dominance of the private automobile is evident. In 1992–93, the car accounted for about 87 per cent of almost 158 billion urban motorised passenger-kilometres while the public transport share was less than 8 per cent (with bus at 3 per cent, rail at 4.6 per cent and ferry at 0.2 per cent). Passenger-kilometres are calculated as the product of the number of passengers by the distance travelled.

Non-motorised travel (walking and cycling) forms a significant proportion of the total number of trips undertaken in urban areas, but only accounts for a small share of total urban passenger-kilometres. Between 2 and 4 per cent of urban trips are by bicycle. Since the average trip length for urban cycling is only 2.5 kilometres (Adena & Montesin 1988, pp. 131–132), bicycle trips account for less than 1 per cent of total urban pkm. Bicycle travel is approximately evenly split between children travelling 2 kilometres at a time, generally to school, and adults travelling about 3.5 kilometres a time (Wigan 1994a, p. 5).

Most journeys involve some walking. For example, a journey to work may consist of the following trip segments (a component of a journey undertaken by a distinct mode): car trip to parking lot, walk to bus terminal, bus trip to inner-city bus stop, walk to work location. On the basis of the number of urban trip segments, walking accounts for a considerable share (up to 20 per cent of total trips). Around 6 per cent of journeys to work are undertaken solely on foot (ABS 1991a). However, the average trip length for walking is less than 1 kilometre, and pedestrians account for less than 2 per cent of total urban passenger-kilometres (Adena & Montesin 1988, p. 132).

Although distances are typically short for walking trips, the slow average speed of 4.7 kilometres per hour for pedestrians (Wigan 1994b, p. 8) can result in walking accounting for a substantial portion of the total time spent travelling. For Australians aged in their mid-20s, time spent walking is around 10 per cent of daily travel time, while for 9- to 15 year-olds and those over 65 walking accounts for around 20 per cent (Wigan 1994b, p. 12).

Time series data are not readily available for non-motorised travel, but it does appear that the transport shares of walking and cycling have declined slightly over the last twenty years. Between 1970 and 1980, non-motorised journeys to work accomplished solely by walking or

TABLE I.5 MID-YEAR POPULATION PROJECTIONS FOR MAJOR AUSTRALIAN CITIES

(millions of people)

Year ending June	*Sydney*	*Melbourne*	*Brisbane*	*Adelaide*	*Perth*	*Canberra*
1995	3.754	3.210	1.469	1.080	1.251	0.303
1996	3.788	3.238	1.497	1.087	1.276	0.307
1997	3.825	3.272	1.525	1.095	1.303	0.312
1998	3.863	3.308	1.554	1.103	1.329	0.318
1999	3.901	3.344	1.582	1.111	1.356	0.323
2000	3.939	3.379	1.611	1.119	1.383	0.328
2001	3.976	3.415	1.639	1.127	1.409	0.333
2002	4.013	3.449	1.668	1.134	1.436	0.339
2003	4.050	3.483	1.696	1.141	1.463	0.344
2004	4.086	3.517	1.724	1.148	1.489	0.349
2005	4.122	3.550	1.753	1.155	1.516	0.355
2006	4.157	3.582	1.781	1.161	1.543	0.360
2007	4.191	3.613	1.809	1.167	1.569	0.365
2008	4.225	3.644	1.836	1.173	1.596	0.370
2009	4.258	3.674	1.864	1.179	1.622	0.375
2010	4.291	3.703	1.891	1.185	1.648	0.380
2011	4.323	3.732	1.918	1.191	1.674	0.385
2012	4.355	3.760	1.945	1.196	1.701	0.390
2013	4.387	3.788	1.972	1.202	1.727	0.395
2014	4.418	3.816	1.998	1.207	1.753	0.400
2015	4.449	3.843	2.025	1.212	1.778	0.405

Note Assumptions made included the following: Total fertility rates (children per 1000 women of childbearing age over childbearing life) for each city were based on the sum of average age-specific fertility rates observed in each of the capital cities between 1987 and 1993. Mortality assumptions were based on projected state mortality rates used in the latest ABS population projections (1994b). These rates were calculated using the historical state-specific short-term rate of mortality decline up to 2000; after that according to the Australian long-term rate of mortality decline. Projected state mortality rates were adjusted to reflect any recent historical difference in the mortality experience of each city. Assumed net migration for each city was based on each city's trends of inter-regional and overseas migration from 1987 to 1994, anticipated future changes to these trends, projected state trends, and the national immigration program. Age/sex distributions for overseas and inter-regional migration were based on 1986 and 1991 Population Census movement data for each capital city. The projections are not intended as predictions or forecasts. They are illustrations of growth and change in the population which would occur if the assumptions about future demographic trends prevail over the projection period.

Source Projections provided on 19 June 1995 by the ABS on contract to the BTCE, using assumptions agreed to by the BTCE.

TABLE I.6 AUSTRALIAN URBAN MOTORISED PASSENGER TASK

(10^9 passenger-kilometres)

Year ending June	Road							
	Car[a]	LCV	Truck	Bus	Motor-cycle	Rail[b]	Ferry	Total
1971	66.50	2.21	0.41	3.50	0.66	7.32	0.16	80.76
1972	69.85	2.57	0.42	3.51	0.72	6.61	0.16	83.84
1973	71.79	3.01	0.42	3.66	0.78	6.23	0.15	86.04
1974	76.34	3.60	0.44	3.80	0.85	6.30	0.15	91.48
1975	80.54	4.13	0.44	3.89	0.91	6.01	0.18	96.10
1976	82.62	4.71	0.44	3.91	1.07	5.96	0.19	98.91
1977	88.07	5.21	0.41	3.97	1.05	5.86	0.18	104.76
1978	91.14	5.59	0.39	4.00	1.09	5.71	0.15	108.06
1979	92.84	6.10	0.36	4.06	1.11	5.67	0.14	110.27
1980	93.36	5.69	0.39	4.19	1.20	6.13	0.13	111.09
1981	94.67	5.59	0.42	4.16	1.29	6.29	0.15	112.57
1982	100.06	5.62	0.44	4.19	1.36	6.46	0.17	118.30
1983	100.29	5.44	0.42	4.17	1.40	6.30	0.18	118.19
1984	104.53	5.85	0.39	4.15	1.43	6.35	0.19	122.89
1985	113.88	6.38	0.37	4.26	1.47	6.43	0.20	132.99
1986	117.76	6.24	0.38	4.34	1.43	6.97	0.20	137.32
1987	123.33	6.32	0.37	4.43	1.40	7.18	0.23	143.25
1988	131.32	6.75	0.37	4.51	1.35	7.47	0.24	152.03
1989	134.53	6.61	0.34	4.66	1.41	7.67	0.24	155.48
1990	136.34	6.52	0.31	4.55	1.35	7.47	0.26	156.82
1991	133.72	6.65	0.26	4.62	1.06	7.52	0.26	154.11
1992	134.52	6.41	0.26	4.96	1.09	7.52	0.25	155.04
1993	137.49	6.52	0.27	4.72	1.09	7.18	0.25	157.55

LCV Light commercial vehicle

a. Includes taxis. In 1990–91, taxis comprised around 1.7 per cent of the urban car task.

b. Includes trams. Between 1970–71 and 1992–93, the tram passenger task was of the order of 0.6 billion passenger-kilometres per year, that is, around 8 per cent of the urban rail task.

Note Figures refer to unlinked passenger trips. Urban figures refer to travel wholly within cities of population greater than 40 000 each year.

Sources Apelbaum 1993, pp. 25, 26, 35, 36, 52; Adena & Montesin 1988; Cosgrove & Gargett 1992; ABS 1993a, 1991b, 1989a, 1986b, 1983, 1981a, 1981b, 1978a, 1973; CBCS 1973; BTCE 1991a, 1991b; BTE 1980, 1975, Nelson English, Loxton & Andrews 1988; Newman & Kenworthy 1990; RIC 1990; BTCE 1994a *Indicators* database; BTCE estimates.

cycling decreased from 7.5 per cent of total work journeys to 5.4 per cent for Sydney, and from 10.4 to 5.7 per cent for Melbourne (Newman & Kenworthy 1990). Data from the Transport Study Group of NSW (STSG 1985; Itorralba & Balce 1992) imply that non-motorised travel share for Sydney declined from 20 per cent of morning peak trips in 1971 to be 15 per cent in 1981, but did not reduce any further (and possibly rose slightly) by 1991.

Adjusting the BTCE estimates for the urban motorised passenger task (157.6 billion passsenger-kilometres in 1992–93, from table I.6) upward by 2.7 per cent (derived from Adena & Montesin 1988), to allow for non-motorised travel, gives an estimate of 162 billion passsenger-kilometres for the total urban passenger task in 1992–93, with modal shares of: car 84.9 per cent, light commercial vehicles 4.0 per cent, truck 0.2 per cent, bus 2.9 per cent, motorcycle 0.7 per cent, rail 4.4 per cent, ferry 0.2 per cent, walking 1.9 per cent, and bicycle 0.8 per cent. Although non-motorised travel has a minor share of total urban passenger-kilometres, its share is similar to (or greater than) that of urban taxis, motorcycles or buses.

NON-URBAN PASSENGER

Estimates of the Australian non-urban motorised passenger task are presented in table I.7. The dominance of private car travel is again apparent, with 61.3 per cent of 1992–93 non-urban motorised passenger-kilometres being performed by cars. After cars, the main segments of the 1992–93 task were due to air travel (19 per cent), buses and coaches (11 per cent), and light commercial vehicles (5.5 per cent).

Data reported by Adena and Montesin (1988, pp. 140, 148) imply that non-motorised transport accounts for about 2.6 per cent of day-to-day (that is, not long-distance) travel in non-urban areas (1.3 per cent by walking and 1.3 per cent by bicycle). Interstate travel accounts for about 20 per cent of non-urban motor vehicle-kilometres travelled. Therefore, if we assume that the remaining 80 per cent of non-urban road travel (around 67 billion passsenger-kilometres for 1992–93) approximates non-urban day-to-day travel, we have an estimated non-motorised task of 1.8 billion passsenger-kilometres in non-urban travel for 1992–93. The total (motorised and non-motorised) non-urban passenger task for 1992–93 is thus around 108.2 billion passsenger-kilometres.

INTERNATIONAL FREIGHT

Between 1970–71 and 1992–93 Australia's international freight task increased by approximately 186 per cent in tonne-kilometre terms (details

TABLE I.7 AUSTRALIAN NON-URBAN MOTORISED PASSENGER TASK

(10^9 passenger-kilometres)

	Road								
Year ending June	*Car*	*LCV*	*Truck*	*Bus*	*Motor-cycle*	*Rail*	*Air*[a]	*Sea*[b]	*Total*
1971	41.87	2.63	0.43	3.1	0.46	6.1	5.20	0.54	60.33
1972	42.00	2.93	0.44	3.2	0.49	5.0	5.61	0.54	60.21
1973	42.98	3.29	0.44	3.2	0.54	5.0	6.16	0.54	62.15
1974	45.71	3.76	0.46	3.2	0.58	3.8	7.34	0.54	65.39
1975	48.22	4.12	0.46	3.2	0.63	3.2	7.93	0.54	68.30
1976	49.47	4.50	0.46	3.3	0.74	2.6	7.74	0.55	69.36
1977	49.52	4.76	0.44	3.3	0.79	2.7	7.46	0.54	69.51
1978	51.25	4.84	0.42	3.3	0.82	2.7	8.15	0.54	72.02
1979	52.20	4.98	0.40	3.3	0.83	2.7	8.58	0.54	73.53
1980	53.02	4.84	0.45	3.7	0.89	2.6	9.49	0.54	75.53
1981	53.76	5.01	0.50	4.2	0.91	3.0	9.57	0.55	77.50
1982	56.82	5.22	0.54	4.7	1.00	2.9	10.06	0.55	81.79
1983	56.95	5.13	0.49	6.1	1.02	3.0	9.25	0.55	82.49
1984	59.36	5.50	0.45	7.6	1.05	2.9	9.81	0.55	87.22
1985	57.26	6.04	0.41	9.0	1.03	3.0	10.59	0.61	87.94
1986	59.49	5.55	0.38	9.9	0.88	2.7	11.47	0.57	90.94
1987	57.61	5.26	0.34	10.9	0.80	2.7	12.28	0.49	90.38
1988	55.83	5.23	0.31	11.8	0.77	2.9	13.57	0.40	90.81
1989	60.16	5.45	0.31	12.5	0.79	2.9	14.15	0.40	96.66
1990	62.47	5.60	0.30	12.9	0.76	2.5	10.41	0.41	95.35

Continued on next page

TABLE I.7 AUSTRALIAN NON-URBAN MOTORISED PASSENGER TASK (continued)

(10^9 passenger-kilometres)

Year ending June	*Road*								
	Car	*LCV*	*Truck*	*Bus*	*Motor-cycle*	*Rail*	*Air*[a]	*Sea*[b]	*Total*
1991	61.27	5.93	0.23	12.3	0.72	2.5	15.66	0.39	99.00
1992	63.75	5.75	0.23	11.4	0.74	2.3	20.24	0.38	104.79
1993	65.16	5.84	0.24	11.7	0.74	2.2	20.15	0.38	106.41

LCV Light commercial vehicle

a. Includes general aviation. The strong decline in 1989–90 air travel was due to the airline pilots' dispute.

b. Cruises and Bass Strait ferries.

Note Figures refer to unlinked trips. Non-urban figures refer to all passenger movements except those wholly within cities of population greater than 40 000 each year.

Sources Apelbaum 1993, pp 25, 36, 49, 52, 166; ABS 1993a, 1991b, 1989a, 1986b, 1983, 1981a, 1981b, 1978a, 1973; CBCS 1973; BTCE 1991a, 1991b; Cosgrove & Gargett 1992; BTE 1980, 1975; DOTC 1991b; Nelson English, Loxton & Andrews 1988; Transport Tasmania pers. comm.1993, 1990; BTCE 1994a *Indicators* database; BTCE estimates.

of the calculation of international tonne-kilometres from import and export tonnages are given in BTCE 1995c, pp. 102, 245).

Shipping is by far the dominant carrier for both exports and imports in terms of tonne-kilometres performed. In 1992–93, the export freight task was more than 10 times the level of imports (see table I.8). For import tonne-kilometres in 1992–93, bulk commodities accounted for 78.5 per cent and non-bulk for 21.5 per cent; while for exports, bulk comprised 97 per cent and non-bulk 3 per cent. The bulk share of total international shipping for 1992–93 (4331 billion tonne-kilometres) is therefore about 95.4 per cent.

Air freight is mainly carried on scheduled passenger services and the goods are typically high value, small volume and perishable in nature (BTCE 1991a). Unlike sea freight, import and export levels carried by air are of similar proportions. Between 1971 and 1993 total international air freight in tonne-kilometres increased by more than 14 times.

INTERNATIONAL PASSENGER TRANSPORT

In contrast to international freight, international passenger movements are undertaken almost exclusively by air (table I.9). The number of passenger-kilometres travelled to and from Australia in 1992–93 was over six times greater than in 1970–71 (details of the calculation of international passenger-kilometres from passenger arrivals and departures are given in BTCE 1995c, p. 86). Since net immigration (permanent international arrivals minus permanent international departures, typically less than 1 per cent) is relatively small compared with total international arrivals and departures, passenger flows into and out of Australia, by both sea and air transport, are roughly equivalent.

Foreign tourism to Australia is the fastest growing sector of the aviation market. Since the 1970s, growth in the number of foreign arrivals has averaged 11 per cent per annum, while that of Australian residents departing on overseas trips has been lower at 5.7 per cent per annum (time series provided in BTCE 1995c, appendix X).

Passenger-kilometres due to international sea travel are very small compared with air (at less than 0.4 per cent of total international passsenger-kilometres for 1993), declining significantly since the 1970s.

TABLE I.8 INTERNATIONAL FREIGHT TASK TO AND FROM AUSTRALIA

(10^9 tonne-kilometres)

Year ending June	Air			Sea			
	Imports	Exports	Total	Imports	Exports	Total	Total
1971	0.15	0.10	0.24	231.23	1 282.69	1 513.92	1 514.16
1972	0.16	0.13	0.29	210.65	1 383.00	1 593.66	1 593.94
1973	0.22	0.16	0.38	217.80	1 694.23	1 912.04	1 912.42
1974	0.35	0.20	0.55	248.99	1 926.03	2 175.02	2 175.57
1975	0.41	0.25	0.66	236.44	2 110.28	2 346.73	2 347.39
1976	0.47	0.28	0.75	212.95	1 998.50	2 211.46	2 212.21
1977	0.49	0.29	0.78	221.98	2 110.71	2 332.69	2 333.47
1978	0.54	0.35	0.89	234.48	2 105.14	2 339.63	2 340.52
1979	0.66	0.46	1.12	236.35	2 113.20	2 349.55	2 350.67
1980	0.70	0.52	1.22	274.70	2 398.44	2 673.14	2 674.36
1981	0.68	0.52	1.21	289.08	2 284.97	2 574.05	2 575.26
1982	0.86	0.65	1.50	278.31	2 257.64	2 535.94	2 537.44
1983	0.86	0.73	1.59	256.99	2 193.15	2 450.14	2 451.72
1984	1.04	0.81	1.84	244.07	2 682.33	2 926.40	2 928.25
1985	1.12	0.93	2.05	250.99	3 161.93	3 412.92	3 414.97
1986	0.99	1.09	2.08	220.04	3 128.98	3 349.03	3 351.11
1987	0.97	1.25	2.22	254.22	3 096.12	3 350.34	3 352.56
1988	1.10	1.19	2.29	299.94	3 472.08	3 772.02	3 774.31
1989	1.50	1.22	2.72	378.54	3 399.98	3 778.52	3 781.24
1990	1.54	1.30	2.84	356.55	3 559.40	3 915.95	3 918.78
1991	1.53	1.36	2.89	362.66	3 883.94	4 246.60	4 249.49
1992	1.58	1.48	3.06	323.12	3 929.64	4 252.76	4 255.82
1993	1.68	1.78	3.46	369.27	3 961.35	4 330.62	4 334.09

Sources ABS 1991c and earlier; BTCE 1994a *Indicators* database; BTCE estimates based on Apelbaum 1993, pp. 64, 67, 68, 161, 169, BTCE 1993d, 1988, CBCS 1973, DOTC 1993 and earlier.

TABLE I.9 INTERNATIONAL PASSENGER TASK TO AND FROM AUSTRALIA

(10^9 passenger-kilometres)

Year ending June	*Air*	*Sea*	*Total*
1971	11.02	1.94	12.96
1972	14.77	1.60	16.37
1973	17.54	1.32	18.86
1974	20.87	1.19	22.06
1975	23.08	0.82	23.90
1976	26.38	0.64	27.02
1977	26.58	0.60	27.18
1978	29.15	0.42	29.57
1979	34.36	0.53	34.89
1980	34.88	0.47	35.35
1981	32.24	0.21	32.45
1982	33.05	0.15	33.20
1983	32.04	0.20	32.24
1984	33.50	0.19	33.69
1985	37.12	0.29	37.41
1986	39.12	0.32	39.44
1987	44.03	0.29	44.32
1988	50.66	0.21	50.87
1989	57.55	0.26	57.81
1990	59.50	0.18	59.68
1991	60.86	0.24	61.10
1992	63.40	0.27	63.67
1993	70.45	0.25	70.70

Notes 1. Figures refer to both inward and outward travel.

2. Passenger flows into and out of Australia, by both sea and air transport, are roughly equivalent, so arrivals or departures can be roughly estimated by dividing the value provided by two.

Sources BTCE 1994a *Indicators* database; BTCE estimates based on Apelbaum 1993, pp. 64, 70, 161, 170, BTCE 1993c, 1988, CBCS 1973, DOTC 1993 and earlier.

APPENDIX II AUSTRALIAN TRANSPORT FUEL PRICES AND CONSUMPTION

This appendix provides estimates of transport fuel consumption by each mode of transport in performing the Australian transport task outlined in appendix I. Fuel consumption is measured in petajoules (PJ) of energy consumed in order to take account of each transport mode using different types of fuel with different energy contents. The energy consumption figures provided are 'end-use'; that is, energy use resulting solely from vehicle operation. The figures do not contain energy consumption involved in the fuel refining process, electricity generation or electricity transmission losses.

Different fuels are consumed by each transport mode. For example, the main fuel consumed by passenger cars is automotive gasoline, commonly called petrol. However small amounts of automotive diesel oil, liquefied petroleum gas (LPG) and compressed natural gas (CNG) are also used for cars. Diesel is the main fuel consumed by trucks, although small quantities of petrol, LPG and CNG are also consumed. The major fuel used for rail transport is automotive diesel oil (ADO). However, industrial diesel fuel (IDF) and electricity are also used. Electricity consumed by rail is used mainly for the movement of urban rail passengers. However a small amount is also used for the movement of government freight (Apelbaum 1993, p. 100). International aviation uses aviation turbine fuel (avtur). The domestic aviation market consumes both aviation gasoline (avgas) and aviation turbine fuel (avtur). Aviation gasoline is used primarily by the general aviation market (commuter and charter services, private and training flights, and aerial agricultural work) while aviation turbine fuel is used primarily by scheduled airline services. Sea transport consumes mainly fuel oil although small quantities of automotive diesel oil and industrial diesel fuel are also used.

Time series estimates for Australian domestic transport energy consumption for each transport mode are provided in table II.1. Due to a lack of detailed data, the time series in the appendix do not separate out military fuel use, do not include pipelines and only include marine fuel use due to coastal shipping (that is, pleasure craft, fishing boats and urban ferries are excluded).

TABLE II.1 AUSTRALIAN DOMESTIC TRANSPORT ENERGY CONSUMPTION BY MODE

(petajoules)

Year ending June	Road	Air	Sea	Rail	Total
1971	392.8	25.9	34.5	21.5	474.7
1972	409.1	27.9	40.0	23.0	500.0
1973	426.3	30.9	43.0	26.0	526.2
1974	455.2	36.4	45.9	27.7	565.2
1975	483.5	39.9	40.1	29.1	592.6
1976	507.3	40.3	36.1	29.9	613.6
1977	537.4	41.5	42.9	29.9	651.7
1978	560.7	44.2	51.6	30.3	686.8
1979	587.9	43.6	43.8	30.9	706.2
1980	597.6	45.3	48.3	30.8	722.0
1981	607.1	45.1	47.9	30.8	730.9
1982	641.4	48.1	38.7	30.6	758.8
1983	630.7	46.7	38.0	28.2	743.6
1984	657.4	46.4	37.4	30.4	771.6
1985	691.5	47.5	34.0	32.1	805.1
1986	703.6	50.8	34.1	31.2	819.7
1987	717.6	52.8	35.6	32.4	838.4
1988	752.6	56.4	34.1	32.3	875.4
1989	779.2	55.9	31.3	30.5	896.9
1990	791.7	45.7	27.0	30.2	894.6
1991	778.2	56.4	22.6	30.0	887.2
1992	794.6	61.1	25.9	29.3	910.9
1993	813.6	63.9	20.1	28.8	926.4

Notes
1. End-use figures. That is, energy consumption resulting solely from vehicle operation.
2. Figures include energy consumption by military transport.
3. Energy use for bunkers, pipelines, fishing and pleasure craft, and ferries is excluded.

Sources Bush et al. 1993; S. Bush, ABARE, pers. comm. December 1994; Apelbaum 1993; BTCE estimates.

For 1992–93, the BTCE has calculated the following detailed sectoral estimates of Australian transport energy consumption (adjusting for the above exclusions):

- 935 PJ for domestic civil transport energy use composed of:
  - 55.9 PJ for domestic aviation (6.0 per cent),
  - 813.6 PJ for the road sector (87 per cent),
  - 32.5 PJ for the maritime sector (3.5 per cent),
  - 28.8 PJ for rail transport (3.1 per cent) and
  - 3.8 PJ for pipelines (0.4 per cent);
- 14.7 PJ for military transport;
- 72.5 PJ for Australian bunker fuel use by international air transport; and
- 24.8 PJ for Australian bunker fuel use by international sea transport.

ROAD TRANSPORT

Energy consumption by road vehicles doubled between 1970–71 and 1992–93. A breakdown of energy consumption by vehicle type is provided in table II.2. Cars accounted for around 64.5 per cent of total energy consumption in 1992–93. Cars are followed by trucks (rigid, articulated, other and light commercial vehicles) with 32.9 per cent, buses with 2.2 per cent and motorcycles with 0.4 per cent.

ROAD PASSENGER TRANSPORT

Cars are the most common road transport vehicle in Australia. With technological progress, new cars tend to be more fuel- and emissions-efficient than older vehicles. Table II.3 shows the characteristics of new vehicles over time. Note that the fuel intensity (litres/100 km) of new vehicles has been falling over time. This has led to a gradual decline in the fuel intensity of the total car fleet, shown in table II.4. Data on the mix of vehicles by fuel type is scarce, but since 1985 there has been a consistent growth in diesel and LPG or CNG vehicles (table II.5). However, the petrol-driven motor car is still the predominant vehicle in the Australian car fleet. Vehicle-kilometres travelled by fuel type of the vehicle reflect this predominance of petrol as a fuel (table II.6), as does estimated total fuel consumption (table II.7).

TABLE II.2 ENERGY CONSUMPTION BY ROAD VEHICLES

(petajoules)

Year ending June	*Cars*	*Motor-cycles*	*LCVs*	*Rigid trucks*	*Articulated trucks*	*Other trucks*	*Buses*	*Total*
1971	268.01	2.05	39.55	45.78	29.64	0.71	7.04	392.78
1972	278.68	2.23	42.01	47.38	30.78	0.85	7.16	409.08
1973	289.30	2.43	45.31	48.90	31.98	0.98	7.34	426.25
1974	308.72	2.63	50.19	51.51	33.34	1.32	7.48	455.19
1975	326.78	2.83	55.07	54.03	35.35	1.76	7.65	483.47
1976	339.65	3.32	60.19	56.36	38.04	2.07	7.70	507.33
1977	356.03	3.40	67.20	57.60	42.31	3.00	7.81	537.35
1978	369.22	3.50	73.36	57.94	45.69	3.13	7.90	560.74
1979	380.59	3.46	79.14	60.30	53.27	3.13	8.03	587.91
1980	382.86	3.71	76.85	65.76	57.36	2.64	8.45	597.62
1981	387.18	3.91	77.01	69.88	57.66	2.60	8.85	607.09
1982	404.77	4.19	80.97	77.62	62.04	2.52	9.28	641.39
1983	403.12	4.22	79.28	69.59	61.82	2.34	10.33	630.71
1984	417.90	4.32	85.01	69.60	66.69	2.48	11.42	657.42
1985	432.24	4.53	93.33	72.33	74.17	2.36	12.58	691.54
1986	444.37	4.18	93.13	71.49	74.64	2.39	13.39	703.58
1987	452.68	3.98	94.91	72.70	76.50	2.56	14.23	717.56
1988	472.38	3.95	102.22	76.37	80.15	2.55	15.01	752.63
1989	495.96	4.04	102.41	75.35	82.88	2.63	15.90	779.17
1990	511.41	3.88	103.01	72.68	82.07	2.31	16.37	791.74
1991	511.60	3.21	106.88	61.84	77.36	1.58	15.70	778.17
1992	518.91	3.34	108.79	65.01	80.83	1.82	15.60	794.58
1993	526.06	3.33	113.20	68.74	84.30	1.76	15.65	813.57

LCVs Light commercial vehicles

Note End-use figures. That is, energy consumption resulting solely from vehicle operation.

Sources Apelbaum 1993; Cosgrove & Gargett 1992; BTCE estimates based on ABS *Survey of Motor Vehicle Use* 1993a and earlier; Bush et al. 1993; BTCE 1994a; Hensher 1989; Wilkenfeld 1991.

TABLE II.3 CHARACTERISTICS OF NEW PASSENGER CARS

Year ending June	*Registrations (thousand)*	*Fuel intensity (litres/100 km)*	*Price ($/vehicle)*
1971	417.2	12.60	2 830
1972	412.5	12.50	2 993
1973	429.7	12.60	3 148
1974	465.0	12.49	3 875
1975	502.7	12.28	4 729
1976	454.6	13.00	5 408
1977	447.1	12.95	6 008
1978	432.4	12.90	6 542
1979	463.5	12.60	7 430
1980	452.0	11.94	8 696
1981	456.6	12.01	9 850
1982	455.5	11.74	10 558
1983	426.4	11.30	11 694
1984	428.7	11.30	12 833
1985	483.2	11.36	14 428
1986	450.9	11.40	18 002
1987	367.1	11.20	20 403
1988	384.2	10.90	21 577
1989	447.9	10.81	22 541
1990	492.2	10.53	23 333
1991	440.8	10.41	24 178
1992	437.0	10.50	24 727
1993	449.8	10.50	27 028
1994	476.0	10.44	28 000
1995	514.7	10.38	29 000
1996	528.1	10.25	30 000
1997	494.6	10.12	
1998	499.8	9.98	
1999	505.3	9.85	
2000	512.4	9.71	
2001	518.3	9.63	
2002	521.1	9.54	
2003	525.3	9.45	
2004	529.1	9.36	
2005	533.3	9.27	
2006	537.0	9.09	
2007	540.3	8.91	
2008	544.0	8.73	
2009	548.3	8.56	
2010	552.7	8.38	
2011	558.0	8.17	
2012	564.4	7.96	
2013	569.4	7.75	
2014	575.2	7.54	
2015	580.7	7.33	

Notes 1. New vehicle prices are sales weighted averages.
2. 1994 and later are estimates.

Sources BTCE 1996a; FCAI pers. comm. October 1995; BTCE estimates.

TABLE II.4 PASSENGER CAR AVERAGE FUEL INTENSITY[a]

(L/100 km)

Year ending June	*Total*	*Gasoline*	*Diesel*	*LPG*
1971	12.28	12.3		
1972	12.32			
1973	12.43			
1974	12.43			
1975	12.44			
1976	12.56	12.6		
1977	12.59			
1978	12.57			
1979	12.69	12.7	9.4	12.1
1980	12.61			
1981	12.56			
1982	12.38	12.5	10.4	17.3
1983	12.27			
1984	12.17			
1985	12.07	12.0	11.4	18.0
1986	12.02			
1987	11.92			
1988	11.83	11.8	11.9	17.4
1989	11.91			
1990	12.00			
1991	12.23	12.0	13.1	16.6
1992	12.20			
1993	12.17			
1994	12.13			
1995	12.08			
1996	12.10			
1997	12.13			
1998	12.14			
1999	12.13			
2000	12.11			
2001	12.08			
2002	12.03			
2003	11.99			
2004	11.94			
2005	11.89			
2006	11.83			
2007	11.77			
2008	11.69			
2009	11.60			
2010	11.51			

Continued on next page

TABLE II.4 PASSENGER CAR AVERAGE FUEL INTENSITY[a] (continued)

(L/100 km)

Year ending June	*Total*	*Gasoline*	*Diesel*	*LPG*
2011	11.40			
2012	11.28			
2013	11.16			
2014	11.02			
2015	10.87			

LPG Liquefied petroleum gas

a. Litres of petrol equivalent (in energy terms) to allow for LPG, diesel and natural gas use.

Notes 1. Estimated on-road fuel intensity based on the ABS *Survey of Motor Vehicle Use*. In 1991, the leaded gasoline fleet had an average intensity of 12.5 L/100 km and the unleaded gasoline fleet had 11.4 L/100 km. In 1991, fuel intensity (L/100 km) by age of vehicle was as follows (dates refer to year of manufacture): up to 1969, 12.7; 1970–1974, 12.8; 1975–1979, 12.9; 1980–1984, 12.6; 1985–1988, 12.1; 1989–1991, 11.5.

2. 1994 and later are estimates.

Sources ABS 1995a, 1994a, 1994b, 1994c, 1993a; Cosgrove & Gargett 1992; BTCE 1995c; BTCE estimates.

Fuel prices are shown in table II.8. The Australian policy of exempting LPG from fuel excise tax has the effect of halving its price relative to petrol and diesel.

Estimates of the factors affecting total fuel use by commercial buses are shown in table II.9.

URBAN PASSENGER TRANSPORT

Table II.10 outlines the consumption of energy by urban passenger transport between 1970–71 and 1992–93. Cars are the largest consumer of energy (97 per cent) followed by buses (2 per cent) and rail (1 per cent). Between 1970–71 and 1992–93, energy use by cars doubled while buses increased their energy use by almost 50 per cent over the same period. The dominance of energy consumption by cars in the urban area reflects the large number of passenger-kilometres travelled relative to other modes (table I.6 in appendix I provides the number of urban passenger-kilometres travelled per year for each mode).

NON-URBAN PASSENGER TRANSPORT

Energy consumption estimates for non-urban passenger transport by vehicle type are provided in table II.11. Cars again dominate energy consumption, accounting for around 67 per cent of total non-urban passenger energy consumption in 1992–93. Air transport was also significant, accounting for around 27 per cent. The remaining modes include bus (5 per cent) and rail (1 per cent). However, changes over time reveal a slightly different picture. Over the period from 1977–78 to 1992–93, the greatest growth in energy consumption by non-urban passenger vehicles occurred in bus transport, increasing around four and a half times. Deregulation of the bus industry in the early 1980s was responsible for a substantial spurt in growth, which has now considerably levelled off. Air transport increased by about 45 per cent, cars increased about 26 per cent and rail transport decreased approximately 15 per cent over the period.

DOMESTIC FREIGHT

Table II.12 provides energy consumption data for the Australian road freight transport sector between 1970–71 and 1992–93. In 1992–93 total energy consumption by road freight transport was around 266 PJ. The urban and non-urban split of energy consumption by freight transport vehicles is fairly even, with non-urban accounting for about 53 per cent.

Light commercial vehicles (LCVs) are responsible for 42 per cent of total energy consumption by road freight transport. In particular, LCVs account for over half of the total urban energy consumption by trucks. However, as noted in appendix I, LCVs represent a minor component of the total road freight task in terms of tonne-kilometres.

Articulated trucks account for around 32 per cent of total road freight energy consumption, but four-fifths of this energy consumption occurs in non-urban areas. Rigid trucks account for around 26 per cent of total energy used, and just over half of rigid truck energy consumption occurs in urban areas.

Breakdowns of fuel type by type of road freight vehicle are given in tables II.13 to II.15. Subsidised LPG has made some inroads into the light commercial vehicle market, but has failed to supplant diesel in the rigid and articulated categories. In the rigid truck category, petrol has been supplanted by diesel. Articulated trucks are almost exclusively diesel.

Energy use by all domestic freight transport between 1970–71 and 1992–93 is presented in table II.16. In 1992–93, it is estimated that 309 PJ of energy was consumed by Australian freight transport (excluding pipelines). Around 86 per cent of this total can be attributed to energy use by the road freight sector. Rail and sea freight transport each account for around 7 per cent. Air freight transport is excluded from the table because freight is generally carried in the hold of passenger service aircraft.

Table II.16 excludes the energy consumed by freight transport via pipelines. However Apelbaum (1993, p. xvii) estimates that in 1990–91 energy expended in the movement of gas or liquids in pipelines was around 3.5 PJ. If pipelines were to be included in the 1991 freight energy use total, they would account for about 1.2 per cent of energy used in freight transport.

INTERNATIONAL FREIGHT

The attribution of consumption of bunker fuel among various countries is still subject to international discussion and agreement. The tables containing data on international freight and passenger energy consumption (tables II.17 and II.18) record fuel uplifted, both in Australia and overseas, in the performance of the international passenger and freight movements both into and out of Australia.

A breakdown of estimates for energy consumption from international sea freight transport to and from Australia is provided in table II.17. Energy consumption by international air freight transport is not provided, as the data cannot be separated from energy consumed by the international passenger task. In 1992–93 around 12 per cent of the energy required to complete Australia's international sea freight transport task was uplifted in Australia. Most of the energy consumed (about 88 per cent) was uplifted outside Australia.

INTERNATIONAL PASSENGERS

Estimates of energy consumption resulting from international passenger movements to and from Australia are provided in table II.18. Total energy used by international passenger transport has increased from around 116 PJ in 1977–78 to 254 PJ in 1992–93, an increase of around 120 per cent. Most of the energy consumed by international air passenger transport was uplifted from outside Australia (70 per cent). Energy consumption by international sea passenger transport is small.

TABLE II.5 PASSENGER CAR NUMBERS

			Vehicles (thousands)			
Year ending June	*Population (millions)*	*Vehicles per thousand persons*	*Total*	*Petrol*	*Diesel*	*LPG or CNG*
1971	13.07	305.8	3 997	3 994	3	0
1972	13.30	317.4	4 222			
1973	13.51	322.8	4 362			
1974	13.72	335.6	4 604			
1975	13.89	350.5	4 869			
1976	14.03	364.1	5 108			
1977	14.19	372.0	5 278			
1978	14.36	380.4	5 462			
1979	14.52	389.3	5 652			
1980	14.69	394.9	5 801			
1981	14.92	403.6	6 022			
1982	15.18	415.6	6 308			
1983	15.39	421.0	6 480			
1984	15.58	429.0	6 683			
1985	15.79	438.6	6 926	6 796	80	50
1986	16.02	443.6	7 106			
1987	16.26	444.5	7 227			
1988	16.52	446.8	7 382	7 187	105	90
1989	16.81	450.5	7 574			
1990	17.07	456.8	7 797			
1991	17.28	463.6	8 012	7 680	160	172
1992	17.48	465.8	8 143			
1993	17.67	468.6	8 280	7 895	175	210
1994	17.84	471.1	8 404			
1995	18.02	476.0	8 579			
1996	18.21	481.1	8 760			
1997	18.40	483.9	8 902			
1998	18.59	486.5	9 043			
1999	18.78	488.9	9 182			
2000	18.98	491.1	9 320			
2001	19.17	493.2	9 454			
2002	19.36	495.0	9 584			
2003	19.55	496.8	9 711			
2004	19.73	498.4	9 834			
2005	19.92	499.8	9 955			
2006	20.10	501.2	10 072			
2007	20.27	502.4	10 185			
2008	20.45	503.5	10 295			
2009	20.62	504.6	10 403			
2010	20.79	505.5	10 508			
2011	20.95	506.4	10 611			
2012	21.12	507.2	10 711			
2013	21.28	508.0	10 810			
2014	21.44	508.7	10 907			
2015	21.60	509.3	11 001			

CNG Compressed natural gas LPG Liquefied petroleum gas

Note 1994 and later are estimates.

Sources ABS 1995a, 1994a, 1993a; Cosgrove & Gargett 1992; BTCE 1995c; BTCE estimates.

TABLE II.6 PASSENGER CAR VEHICLE-KILOMETRES TRAVELLED
(billion km)

Year ending June	*Total*	*Petrol*	*Diesel*	*LPG or CNG*
1971	63.8			
1972	66.1			
1973	68.1			
1974	72.6			
1975	76.8			
1976	79.0			
1977	82.7			
1978	85.9			
1979	87.7			
1980	88.8			
1981	90.3			
1982	95.7			
1983	96.2			
1984	100.6			
1985	105.7	102.6	1.7	1.5
1986	109.5			
1987	112.3			
1988	116.8	112.0	2.1	2.7
1989	121.7			
1990	124.6			
1991	122.3	114.4	3.2	5.0
1992	124.3			
1993	126.4			
1994	130.4			
1995	133.0			
1996	135.8			
1997	138.0			
1998	140.2			
1999	142.3			
2000	144.5			
2001	146.5			
2002	148.6			
2003	150.5			
2004	152.4			
2005	154.3			
2006	156.1			
2007	157.9			
2008	159.6			
2009	161.2			
2010	162.9			
2011	164.5			
2012	166.0			
2013	167.5			
2014	169.1			
2015	170.5			

CNG Compressed natural gas LPG Liquefied petroleum gas

Note 1994 and later are estimates. A constant average VKT per car of 15 500 km per year has been assumed to hold through to 2015.

Sources ABS 1995a, 1994a, 1993a; Cosgrove & Gargett 1992; BTCE 1995c; BTCE estimates.

TABLE II.7 PASSENGER CAR FUEL CONSUMPTION
(petajoules)

Year ending June	*Petrol*	*Diesel*	*LPG*	*CNG*	*Total*
1971	267.7	0.3	0.0	0.0	268.0
1972	278.1	0.4	0.1	0.0	278.7
1973	288.5	0.5	0.3	0.0	289.3
1974	307.7	0.6	0.4	0.0	308.7
1975	325.5	0.7	0.6	0.0	326.8
1976	338.1	0.8	0.7	0.0	339.7
1977	354.4	0.8	0.8	0.0	356.0
1978	367.4	0.8	1.0	0.0	369.2
1979	378.5	0.7	1.4	0.0	380.6
1980	379.2	1.4	2.3	0.0	382.9
1981	382.4	1.7	3.1	0.0	387.2
1982	398.5	2.2	4.1	0.0	404.8
1983	395.6	2.7	4.8	0.0	403.1
1984	408.3	3.9	5.8	0.0	417.9
1985	418.1	7.3	6.8	0.0	432.2
1986	428.0	7.7	8.6	0.0	444.4
1987	433.9	8.5	10.3	0.0	452.7
1988	451.0	9.4	12.0	0.0	472.4
1989	469.8	11.6	14.6	0.0	496.0
1990	480.7	13.5	17.2	0.0	511.4
1991	473.6	16.2	21.5	0.0	511.4
1992	477.6	16.6	24.6	0.1	518.9
1993	480.8	17.3	27.9	0.1	526.1
1994	492.0	17.8	30.9	0.1	540.8
1995	499.6	18.0	31.5	0.2	549.2
1996	511.6	18.2	32.0	0.2	562.0
1997	521.1	18.4	32.6	0.3	572.3
1998	529.9	18.5	33.1	0.3	581.9
1999	537.6	18.7	33.7	0.4	590.5
2000	544.7	18.9	34.3	0.5	598.4
2001	550.6	19.1	34.9	0.6	605.3
2002	555.7	19.3	35.5	0.8	611.3
2003	560.4	19.6	36.1	0.9	617.0
2004	564.8	19.8	36.7	1.2	622.4
2005	568.6	20.0	37.4	1.4	627.4
2006	571.8	20.2	38.0	1.8	631.8
2007	573.9	20.4	38.7	2.2	635.2
2008	575.2	20.6	39.4	2.8	637.9
2009	575.5	20.8	40.0	3.4	639.9
2010	574.9	21.1	40.7	4.3	641.0
2011	573.3	21.3	41.4	5.3	641.3
2012	570.5	21.5	42.2	6.6	640.8
2013	566.5	21.7	42.9	8.2	639.4
2014	561.4	22.0	43.6	10.2	637.2
2015	554.9	22.2	44.4	12.7	634.2

CNG Compressed natural gas LPG Liquefied petroleum gas

Note 1994 and later are estimates.

Sources ABS 1993a and earlier; Bush et al. 1993; BTCE 1995c; BTCE estimates.

TABLE II.8 PASSENGER CAR FUEL PRICES

(cents/litre)

Year ending June	*Gasoline*	*LPG*	*Diesel*	*CNG*	*CPI*
1971	10.00		9.17		17.55
1972	10.53		9.58		18.76
1973	10.63		9.58		19.86
1974	11.92		9.58		22.46
1975	13.76	4.98	10.90		26.21
1976	15.80	7.52	13.00		29.58
1977	16.52	4.50	14.00		33.71
1978	17.05	7.05	16.55		36.89
1979	21.28	9.27	20.25		39.92
1980	29.37	19.71	29.06		43.96
1981	34.64	25.10	35.38		48.09
1982	37.57	22.62	38.35		53.90
1983	43.09	24.90	43.85		59.20
1984	47.46	31.95	48.12		63.82
1985	48.80	25.73	50.49		67.67
1986	50.65	27.59	51.40		73.34
1987	54.15	23.24	54.68		80.17
1988	54.80	21.37	55.60		86.04
1989	51.38	18.88	51.65		92.39
1990	58.61	22.62	58.49		100.00
1991	68.61	27.39	67.14		105.30
1992	65.13	24.28	63.71		107.30
1993	66.32	26.16	66.18		108.40
1994	69.17	25.73	70.19	28.6	110.35
1995	70.89	29.40	71.05	28.6	113.90
1996	74.20[e]				118.73[e]

LPG Liquified petroleum gas
CNG Compressed natural gas
CPI Consumer price index

Notes
1. Gasoline refers to Super Leaded petrol, where values prior to 1978 are estimated using the automotive fuel component of the CPI (consumer price index).
2. Retail prices of LPG prior to 1992 were estimated by using the annual growth in wholesale LPG prices. LPG was not widely used before 1974–75. CNG was not widely used before 1994. Prices quoted are in cents per litre of petrol equivalent.

Sources BTCE 1994a; ABS 1994e.

TABLE II.9 FUEL USE BY COMMERCIAL BUSES

Year ending June	*Vehicle-kilometres travelled (million km)*			Number of vehicles (thousands)	*Energy consumption (petajoules)*		
	Urban	*Non-urban*	*Total*		*Urban*	*Non-urban*	*Total*
1971	356	225	581	17.1	4.6	2.4	7.0
1972	360	232	592	17.4	4.7	2.5	7.2
1973	375	230	605	17.8	4.9	2.5	7.3
1974	391	224	615	18.1	5.1	2.4	7.5
1975	401	228	629	18.5	5.2	2.4	7.7
1976	406	227	633	18.9	5.3	2.4	7.7
1977	414	227	641	19.6	5.4	2.4	7.8
1978	420	228	648	20.3	5.5	2.4	7.9
1979	429	230	658	21.1	5.6	2.5	8.0
1980	444	250	694	21.8	5.8	2.7	8.5
1981	445	287	732	22.5	5.8	3.1	8.9
1982	451	319	770	23.2	5.9	3.4	9.3
1983	453	414	868	25.6	5.9	4.4	10.3
1984	456	513	969	28.0	5.9	5.5	11.4
1985	470	604	1074	30.4	6.1	6.5	12.6
1986	482	665	1148	31.8	6.3	7.1	13.4
1987	495	728	1223	33.2	6.4	7.8	14.2
1988	508	786	1294	34.6	6.6	8.4	15.0
1989	516	830	1347	36.6	6.7	8.9	15.6
1990	501	873	1375	37.7	6.5	9.3	15.9
1991	502	857	1359	38.8	6.5	9.2	15.7
1992	535	806	1341	41.4	7.0	8.6	15.6
1993	516	818	1334	43.2	6.7	8.8	15.5

Notes

1. These estimates are based on various editions of the ABS *Survey of Motor Vehicle Use* (1993a) and the ABS *Motor Vehicle Census* (1995a), and are very approximate. For example, the estimates of energy consumption are calculated using a constant rate of fuel consumption for urban buses (13 MJ/km) and a constant for non-urban buses (10MJ/km). The varying share of total bus travel for each sector over time gives results consistent with the ABS statistics, which have average bus fuel consumption falling slightly from 32.6 L/100 km in 1976 to 29.8 L/100 km in 1991. Of the order of 40 per cent of non-urban kilometres travelled is due to interstate coaches.
2. The data refer to commercial buses, and exclude vehicles under 1.8 tonnes tare—even if they are registered as a bus (in 1991 there were about 12 000 such vehicles, mainly petrol powered, which were included in BTCE estimates for light passenger vehicles). The current commercial bus fleet is predominantly (over 80 per cent) diesel powered—in 1991 total fuel consumption consisted of 388 ML of diesel, 18 ML of petrol, 2ML of LPG and 0.03 PJ of natural gas. The situation was quite different in 1971, when just under half of all commercial buses were petrol-driven and petrol buses accounted for around a third of the total energy consumption.

TABLE II.10 ENERGY CONSUMPTION BY URBAN PASSENGER TRANSPORT

(petajoules)

Year ending June	*Car*	*Bus*	*Rail*	*Total*
1971	171.37	4.63	na	na
1972	181.14	4.67	na	na
1973	188.32	4.87	na	na
1974	200.96	5.08	na	na
1975	212.72	5.22	na	na
1976	221.10	5.27	na	na
1977	236.78	5.39	na	na
1978	245.55	5.46	3.89	254.90
1979	253.11	5.57	3.80	262.48
1980	253.78	5.77	4.03	263.58
1981	256.65	5.78	4.07	266.50
1982	268.30	5.86	4.10	278.26
1983	267.21	5.89	3.92	277.02
1984	277.01	5.93	3.88	286.82
1985	298.03	6.11	3.85	307.99
1986	306.39	6.27	4.03	316.69
1987	319.59	6.44	4.00	330.03
1988	342.55	6.60	4.01	353.16
1989	354.61	6.83	4.08	365.52
1990	363.10	6.67	3.93	373.70
1991	363.24	6.77	3.91	373.92
1992	364.99	7.27	3.91	376.17
1993	370.20	6.92	3.73	380.85

na Not available

Notes 1. End-use figures. That is, energy consumption resulting solely from vehicle operation.

2. Motorcycles and ferries excluded. In 1991 motorcycles in the urban area consumed 1.9 PJ, and energy consumption for urban ferries was 0.4 PJ (Apelbaum 1993, pp. 78, 108).

Sources Apelbaum 1993; Adena & Montesin 1988; Cosgrove & Gargett 1992; ABS 1993a, 1991b, 1989a, 1986b, 1983, 1981a, 1981c, 1978a, 1973; CBCS 1973, BTCE 1991a, 1991b; BTE 1980, 1975; Nelson English, Loxton & Andrews 1988; Newman & Kenworthy 1990; RIC 1990; BTCE 1994a; BTCE estimates.

TABLE II.11 ENERGY CONSUMPTION BY NON-URBAN PASSENGER TRANSPORT

(petajoules)

Year ending June	*Car*	*Bus*	*Rail*	*Air*	*Total*
1971	96.64	2.41	na	na	na
1972	97.54	2.48	na	na	na
1973	100.98	2.46	na	na	na
1974	107.76	2.40	na	36.4	na
1975	114.06	2.44	na	39.9	na
1976	118.55	2.43	na	40.3	na
1977	119.25	2.42	na	41.5	na
1978	123.67	2.44	2.76	44.2	173.07
1979	127.48	2.46	2.60	43.6	176.14
1980	129.08	2.68	2.48	45.3	179.54
1981	130.53	3.07	2.72	45.1	181.42
1982	136.46	3.42	2.63	48.1	190.61
1983	135.91	4.44	2.69	46.7	189.74
1984	140.89	5.49	2.60	46.4	195.38
1985	134.21	6.47	2.66	47.5	190.84
1986	137.98	7.12	2.41	50.8	198.31
1987	133.09	7.79	2.38	52.8	196.06
1988	129.82	8.41	2.54	56.4	197.17
1989	141.35	8.48	2.68	55.9	208.41
1990	148.31	9.50	2.48	45.7	205.99
1991	148.36	9.23	2.60	56.4	216.59
1992	154.20	9.79	2.42	61.1	227.51
1993	156.40	11.08	2.34	63.9	233.72

na Not available

Notes
1. End-use figures. That is, energy consumption resulting solely from vehicle operation.
2. Air energy consumption is from scheduled airline services
3. Motorcycles and sea transport excluded. In 1991 motorcycles in non-urban areas consumed 1.3 PJ (Apelbaum 1993, pp. 78, 108).
4. In 1991, the passenger task due to urban ferries was of similar size to that of non-urban sea transport (coastal cruises and Bass Strait ferries) (Apelbaum 1993, p. 52).

Sources Apelbaum 1993; ABS 1993a, 1991b, 1990, 1989a, 1986b, 1983, 1981a, 1981b, 1978, 1973; CBCS 1972; BTCE 1991a, 1991b; Cosgrove & Gargett 1992; BTE 1980, 1975; DOTC 1991b; Nelson English Loxton & Andrews 1988; Transport Tasmania 1993, pers. comm. 1990; BTCE 1994a; BTCE estimates.

TABLE II.12 ENERGY CONSUMPTION BY ROAD FREIGHT TRUCKS

(petajoules)

	Articulated			*Rigid*			*LCVs*		
Year ending June	*Urban*	*Non-urban*	*Total*	*Urban*	*Non-urban*	*Total*	*Urban*	*Non-urban*	*Total*
1971	5.85	23.79	29.64	23.31	22.47	45.78	21.57	17.98	39.55
1972	6.39	24.39	30.78	24.30	23.07	47.38	23.58	18.43	42.01
1973	6.96	25.02	31.98	25.28	23.62	48.90	26.15	19.17	45.32
1974	7.60	25.74	33.34	26.83	24.68	51.51	29.73	20.46	50.19
1975	8.42	26.93	35.35	28.36	25.67	54.03	33.45	21.62	55.07
1976	9.47	28.56	38.04	29.77	26.59	56.36	38.91	22.67	61.58
1977	10.52	31.79	42.31	29.80	27.80	57.60	42.14	25.06	67.20
1978	11.34	34.35	45.69	29.53	28.41	57.94	46.70	26.66	73.36
1979	13.19	40.09	53.27	30.26	30.03	60.30	50.72	28.42	79.14
1980	14.50	42.85	57.36	33.24	32.51	65.76	47.63	29.22	76.85
1981	14.83	42.83	57.66	35.30	34.58	69.88	46.18	30.84	77.02
1982	16.17	45.87	62.04	40.51	37.11	77.62	46.88	34.09	80.97
1983	15.95	45.87	61.82	36.63	32.96	69.59	45.75	33.53	79.28
1984	17.11	49.59	66.69	36.95	32.65	69.60	48.76	36.25	85.01
1985	20.70	53.46	74.17	40.32	32.01	72.33	50.38	42.95	93.33
1986	18.96	55.68	74.64	39.90	31.60	71.49	55.13	37.99	93.12
1987	19.53	56.98	76.50	42.38	30.32	72.70	57.88	37.03	94.91
1988	23.84	56.31	80.15	48.89	27.47	76.37	59.83	42.39	102.22
1989	20.23	62.65	82.88	44.99	30.37	75.35	63.89	40.32	104.21
1990	19.15	62.92	82.07	43.46	29.22	72.68	61.96	41.06	103.02
1991	20.33	57.03	77.36	37.13	24.71	61.84	60.31	46.58	106.89
1992	17.17	63.66	80.83	37.81	27.20	65.01	65.40	43.39	108.79
1993	17.77	66.53	84.30	39.98	28.76	68.74	68.05	45.15	113.20

LCVs Light commercial vehicles

Notes 1. End-use figures. That is, energy consumption resulting solely from vehicle operation.

2. 'Other trucks' are not included since they do not carry freight.

Sources ABS 1993a, 1993b, 1992b, 1986b, 1983, 1981a, 1978a, 1973; Apelbaum 1993; Cosgrove & Gargett 1992; BTCE 1991a, 1991b; BTE 1980, 1975; BTCE estimates.

TABLE II.13 LIGHT COMMERCIAL VEHICLE FUEL CONSUMPTION
(petajoules)

Year ending June	*Petrol*	*Diesel*	*LPG*	*CNG*	*Total*
1971	38.17	1.39	0.00	0.00	39.56
1972	40.54	1.48	0.00	0.00	42.02
1973	43.73	1.59	0.00	0.00	45.32
1974	48.43	1.76	0.00	0.00	50.20
1975	53.14	1.93	0.00	0.00	55.08
1976	58.14	2.05	0.00	0.00	60.19
1977	59.75	7.49	0.00	0.00	67.24
1978	65.23	8.18	0.00	0.00	73.41
1979	70.36	8.82	0.00	0.00	79.19
1980	68.33	8.57	0.00	0.00	76.89
1981	68.47	8.59	0.00	0.00	77.06
1982	71.99	9.03	0.00	0.00	81.02
1983	70.49	8.84	0.00	0.00	79.33
1984	75.59	9.48	0.00	0.00	85.07
1985	78.42	13.63	1.29	0.00	93.33
1986	78.25	13.60	1.28	0.00	93.13
1987	79.75	13.86	1.31	0.00	94.91
1988	80.23	19.65	2.34	0.00	102.22
1989	81.80	20.03	2.38	0.00	104.21
1990	80.86	19.80	2.36	0.00	103.01
1991	77.26	23.70	5.89	0.00	106.84
1992	76.74	25.55	6.44	0.04	108.76
1993	79.49	26.60	6.99	0.07	113.14
1994	83.54	26.60	7.54	0.25	117.92
1995	86.80	27.63	8.09	0.45	122.98
1996	91.70	29.19	8.79	0.84	130.52
1997	97.50	31.04	9.60	1.57	139.71
1998	103.07	32.81	10.42	2.94	149.25
1999	107.95	34.36	11.25	5.50	159.07
2000	110.64	35.22	12.70	10.26	168.82
2001	117.24	37.32	13.49	11.27	179.32
2002	124.10	39.51	14.32	12.36	190.28
2003	131.04	41.71	15.16	13.53	201.44
2004	138.05	43.95	16.02	14.78	212.79
2005	145.35	46.27	16.91	16.13	224.67
2006	152.46	48.53	17.79	17.55	236.33
2007	158.81	50.56	18.59	18.96	246.91
2008	164.66	52.42	19.33	20.38	256.79
2009	170.36	54.23	20.07	21.87	266.54
2010	175.83	55.97	20.78	23.42	276.00
2011	181.35	57.73	21.51	25.06	285.65
2012	187.02	59.54	22.26	26.81	295.63
2013	193.62	61.64	23.13	28.80	307.19
2014	200.53	63.84	24.05	30.96	319.38
2015	208.10	66.25	25.06	33.35	332.76

LPG Liquefied petroleum gas CNG Compressed natural gas

Note 1994 and later are estimates.

Sources ABS 1993a and earlier issues; Bush et al. 1993; BTCE 1995; BTCE estimates.

TABLE II.14 RIGID TRUCK FUEL CONSUMPTION
(petajoules)

Year ending June	*Petrol*	*Diesel*	*LPG*	*CNG*	*Total*
1971	34.20	11.58	0.00	0.00	45.78
1972	34.96	12.41	0.00	0.00	47.38
1973	35.61	13.30	0.00	0.00	48.90
1974	37.28	14.23	0.00	0.00	51.51
1975	38.70	15.34	0.00	0.00	54.03
1976	39.26	17.10	0.00	0.00	56.36
1977	38.03	19.57	0.00	0.00	57.60
1978	36.19	21.75	0.00	0.00	57.94
1979	34.17	26.13	0.00	0.00	60.30
1980	33.17	32.59	0.00	0.00	65.76
1981	33.24	36.64	0.00	0.00	69.88
1982	34.54	43.08	0.00	0.00	77.62
1983	28.46	41.13	0.00	0.00	69.59
1984	25.23	44.37	0.00	0.00	69.60
1985	23.73	48.60	0.00	0.00	72.33
1986	21.27	50.22	0.00	0.00	71.49
1987	19.78	52.92	0.00	0.00	72.70
1988	19.39	56.97	0.00	0.00	76.37
1989	15.81	59.54	0.00	0.00	75.35
1990	12.33	60.35	0.00	0.00	72.68
1991	8.07	54.27	0.00	0.02	61.84
1992	8.55	56.97	0.00	0.02	65.01
1993	8.89	60.37	0.00	0.03	68.74
1994	7.20	60.02	1.62	0.03	68.87
1995	7.36	61.41	1.66	0.04	70.47
1996	7.48	62.50	1.68	0.05	71.71
1997	7.61	63.72	1.71	0.07	73.11
1998	7.75	64.91	1.75	0.08	74.48
1999	7.87	66.08	1.78	0.10	75.83
2000	7.99	67.24	1.80	0.12	77.15
2001	8.10	68.38	1.83	0.15	78.47
2002	8.20	69.52	1.86	0.19	79.77
2003	8.29	70.64	1.89	0.24	81.06
2004	8.37	71.76	1.92	0.29	82.34
2005	8.44	72.86	1.95	0.36	83.61
2006	8.49	73.92	1.97	0.44	84.83
2007	8.51	74.94	2.00	0.55	86.00
2008	8.50	75.92	2.02	0.68	87.13
2009	8.46	76.86	2.05	0.83	88.20
2010	8.38	77.76	2.07	1.03	89.23
2011	8.26	78.71	2.09	1.26	90.32
2012	8.09	79.72	2.12	1.56	91.48
2013	7.86	80.79	2.14	1.92	92.71
2014	7.54	81.90	2.17	2.37	93.99
2015	7.13	83.08	2.20	2.93	95.34

LPG Liquefied petroleum gas CNG Compressed natural gas

Note 1994 and later are estimates.

Sources ABS 1993a and earlier issues; Bush et al. 1993; BTCE 1995c; BTCE estimates.

TABLE II.15 ARTICULATED TRUCK FUEL CONSUMPTION
(petajoules)

Year ending June	*Petrol*	*Diesel*	*LPG*	*CNG*	*Total*
1971	5.47	24.16	0.00	0.00	29.64
1972	4.88	25.90	0.00	0.00	30.78
1973	4.21	27.77	0.00	0.00	31.98
1974	3.59	29.75	0.00	0.00	33.34
1975	3.03	32.32	0.00	0.00	35.35
1976	2.29	35.74	0.00	0.00	38.04
1977	2.09	40.22	0.00	0.00	42.31
1978	1.74	43.95	0.00	0.00	45.69
1979	1.47	51.80	0.00	0.00	53.27
1980	1.30	56.06	0.00	0.00	57.36
1981	1.18	56.48	0.00	0.00	57.66
1982	1.13	60.91	0.00	0.00	62.04
1983	0.91	60.91	0.00	0.00	61.82
1984	0.70	65.99	0.00	0.00	66.69
1985	0.48	73.69	0.00	0.00	74.17
1986	0.45	74.19	0.00	0.00	74.64
1987	0.43	76.07	0.00	0.00	76.50
1988	0.44	79.71	0.00	0.00	80.15
1989	0.30	82.58	0.00	0.00	82.88
1990	0.31	81.77	0.00	0.00	82.07
1991	0.27	77.08	0.00	0.00	77.36
1992	0.27	80.56	0.00	0.00	80.83
1993	0.31	83.99	0.00	0.00	84.30
1994	0.80	83.48	0.00	0.00	84.28
1995	0.82	85.86	0.00	0.00	86.68
1996	0.84	88.08	0.00	0.00	88.92
1997	0.87	90.40	0.00	0.00	91.27
1998	0.89	92.56	0.00	0.00	93.44
1999	0.91	94.99	0.00	0.00	95.90
2000	0.93	97.51	0.00	0.00	98.44
2001	0.96	100.07	0.00	0.00	101.03
2002	0.98	102.69	0.00	0.00	103.67
2003	1.01	105.32	0.00	0.00	106.33
2004	1.04	108.10	0.00	0.00	109.13
2005	1.06	110.89	0.00	0.00	111.96
2006	1.09	113.92	0.00	0.00	115.02
2007	1.12	117.03	0.00	0.00	118.15
2008	1.15	120.35	0.00	0.00	121.50
2009	1.19	123.75	0.00	0.00	124.94
2010	1.22	127.54	0.00	0.00	128.76
2011	1.26	131.26	0.00	0.00	132.52
2012	1.30	135.17	0.00	0.00	136.46
2013	1.33	139.31	0.00	0.00	140.64
2014	1.38	143.77	0.00	0.00	145.15
2015	1.32	147.91	0.00	0.00	149.23

LPG Liquefied petroleum gas CNG Compressed natural gas

Note 1994 and later are estimates.

Sources ABS 1993a and earlier issues; Bush et al. 1993; BTCE 1995c; BTCE estimates.

TABLE II.16 AUSTRALIAN DOMESTIC FREIGHT ENERGY CONSUMPTION (EXCLUDING PIPELINES)

(petajoules)

Year ending June	*Road*		*Rail*	*Sea*	*Total*
	Urban	*Non-urban*			
1971	50.73	64.24	na	34.50	na
1972	54.28	65.89	na	40.00	na
1973	58.39	67.81	na	43.00	na
1974	64.16	70.88	na	45.90	na
1975	70.23	74.23	na	40.10	na
1976	78.15	77.83	na	36.10	na
1977	82.47	84.65	na	42.90	na
1978	87.57	89.42	23.65	51.60	252.24
1979	94.17	98.54	24.50	43.80	261.01
1980	95.38	104.59	24.29	48.30	272.55
1981	96.31	108.25	24.01	47.90	276.46
1982	103.57	117.06	23.87	38.70	283.20
1983	98.34	112.36	21.59	38.00	270.28
1984	102.82	118.48	23.92	37.40	282.63
1985	111.40	128.43	25.59	34.00	299.42
1986	113.99	125.27	24.76	34.10	298.12
1987	119.79	124.33	26.02	35.60	305.73
1988	132.56	126.17	25.75	34.10	318.59
1989	129.11	133.34	23.74	31.30	317.48
1990	124.57	133.20	23.79	27.00	308.56
1991	117.78	128.31	23.49	22.60	292.17
1992	120.38	134.25	22.97	25.90	303.51
1993	125.80	140.44	22.73	20.10	309.07

na Not available

Notes
1. End-use figures. That is, energy consumption resulting solely from vehicle operation.
2. Air transport is excluded from this table as air freight is generally carried on passenger services.

Sources Apelbaum 1993; ABS 1993a, 1991b, 1986b, 1983, 1981a, 1981b, 1978a, 1973; CBCS 1973; BTCE 1991a, 1991b, 1989; BTE 1982a, 1980, 1975; DOTC 1991a, 1991b; Cosgrove & Gargett 1992, p. 234; BTCE 1994a; BTCE estimates.

TABLE II.17 ENERGY CONSUMPTION DUE TO INTERNATIONAL SEA FREIGHT MOVEMENTS TO AND FROM AUSTRALIA

(petajoules)

Year ending June	*Uplifted in Australia*	*Uplifted outside Australia*	*Total*
1971	75.2	na	na
1972	66.9	na	na
1973	60.7	na	na
1974	55.4	na	na
1975	62.4	na	na
1976	59.3	na	na
1977	49.2	na	na
1978	48.7	na	na
1979	34.7	na	na
1980	36.2	na	na
1981	30.5	na	na
1982	30.2	na	na
1983	36.2	230.3	266.5
1984	30.5	198.5	229.0
1985	30.2	251.0	281.2
1986	20.6	196.4	217.0
1987	21.9	193.4	215.3
1988	24.8	193.0	217.8
1989	28.0	214.0	242.0
1990	28.6	211.9	240.5
1991	28.8	231.8	260.6
1992	24.9	198.9	223.7
1993	24.8	199.2	224.0

na Not available

Notes
1. End-use figures. That is, energy consumption resulting solely from vehicle operation.
2. Air transport is not included in the table as freight and passenger energy consumption data cannot be differentiated (since most air freight is carried on passenger services).

Sources ABS 1991c and earlier; BTCE 1994a; BTCE estimates based on: Apelbaum 1993; BTCE 1993c, 1988; CBCS 1972; DOTC 1993b and earlier.

TABLE II.18 ENERGY CONSUMPTION DUE TO INTERNATIONAL PASSENGER MOVEMENTS TO AND FROM AUSTRALIA

(petajoules)

	Air			*Sea*		
Year ending June	*Uplifted in Australia*	*Uplifted outside Australia*	*Total*	*Uplifted in Australia*	*Uplifted outside Australia*	*Total*
1971	na	na	na	na	na	na
1972	na	na	na	na	na	na
1973	na	na	na	na	na	na
1974	na	na	na	na	na	na
1975	na	na	na	na	na	na
1976	na	na	na	na	na	na
1977	na	na	na	na	na	na
1978	34.16	81.34	115.50	na	na	na
1979	33.62	80.05	113.67	na	na	na
1980	35.07	83.51	118.58	na	na	na
1981	34.95	83.21	118.16	na	na	na
1982	37.49	89.27	126.76	na	na	na
1983	36.50	86.90	123.40	1.06×10^{-4}	5.67×10^{-4}	6.72×10^{-4}
1984	36.41	86.70	123.11	9.73×10^{-5}	5.36×10^{-4}	6.33×10^{-4}
1985	41.00	97.62	138.62	1.01×10^{-4}	7.35×10^{-4}	8.36×10^{-4}
1986	41.82	99.57	141.39	6.67×10^{-5}	5.68×10^{-4}	6.35×10^{-4}
1987	44.16	105.15	149.31	6.60×10^{-5}	5.17×10^{-4}	5.83×10^{-4}
1988	49.95	118.92	168.87	6.99×10^{-5}	4.75×10^{-4}	5.45×10^{-4}
1989	57.67	137.30	194.97	7.36×10^{-5}	4.89×10^{-4}	5.63×10^{-4}
1990	62.99	149.97	212.96	7.91×10^{-5}	5.07×10^{-4}	5.86×10^{-4}
1991	65.53	156.01	221.54	6.79×10^{-5}	4.79×10^{-4}	5.46×10^{-4}
1992	69.52	165.52	235.04	6.93×10^{-5}	4.85×10^{-4}	5.55×10^{-4}
1993	75.15	178.92	254.07	6.84×10^{-5}	4.82×10^{-4}	5.51×10^{-4}

na Not available

Note End-use figures. That is, energy consumption resulting solely from vehicle operation.

Sources BTCE 1994a; BTCE estimates based on: Apelbaum 1993, pp. 64, 70, 161, 170; BTCE 1993d, 1988; DOTC 1993 and earlier.

APPENDIX III BASECASE EMISSION PROJECTIONS

TABLE III.1 BASECASE ROAD EMISSIONS BY VEHICLE TYPE

(thousand tonnes of CO_2 equivalent)

Year	*Cars*	*Motor-cycles*	*Buses*	*LCVs*	*Rigid and other trucks*	*Articulated trucks*	*Total*
1971	25 451	211	519	3 103	3 558	2 272	35 114
1972	26 439	228	528	3 296	3 678	2 359	36 528
1973	27 379	249	541	3 555	3 792	2 451	37 968
1974	29 212	270	552	3 938	3 992	2 556	40 520
1975	30 917	291	564	4 320	4 184	2 710	42 986
1976	32 043	341	568	4 722	4 458	2 916	45 047
1977	33 437	349	576	5 229	4 431	3 243	47 265
1978	34 543	359	583	5 708	4 438	3 502	49 134
1979	35 352	368	592	6 158	4 587	4 083	51 140
1980	35 474	395	623	5 979	4 965	4 397	51 833
1981	35 695	415	653	5 992	5 258	4 420	52 433
1982	37 272	453	685	6 300	5 818	4 756	55 284
1983	36 981	457	762	6 169	5 194	4 739	54 301
1984	38 222	467	842	6 615	5 165	5 112	56 423
1985	39 443	473	928	7 262	5 345	5 685	59 136
1986	40 183	436	987	7 229	5 263	5 721	59 820
1987	40 248	415	1 049	7 368	5 335	5 864	60 279
1988	41 454	399	1 107	7 935	5 591	6 144	62 631
1989	42 793	415	1 173	8 008	5 487	6 353	64 228
1990	43 599	399	1 208	8 055	5 266	6 291	64 817

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TABLE III.1 BASECASE ROAD EMISSIONS BY VEHICLE TYPE (continued)

(thousand tonnes of CO_2 equivalent)

Year	Cars	Motor-cycles	Buses	LCVs	Rigid and other trucks	Articulated trucks	Total
1991	42 978	334	1 158	8 357	4 494	5 930	63 252
1992	43 429	334	1 148	8 490	4 731	6 203	64 335
1993	43 769	334	1 149	8 830	5 002	6 468	65 552
1994	44 733	334	1 159	9 203	5 093	6 573	67 095
1995	45 185	334	1 168	9 592	5 200	6 761	68 242
1996	46 009	334	1 178	9 996	5 305	6 936	69 759
1997	46 566	334	1 188	10 653	5 408	7 122	71 272
1998	47 057	334	1 199	11 297	5 508	7 294	72 689
1999	47 493	334	1 209	11 886	5 606	7 490	74 019
2000	47 893	334	1 220	12 328	5 703	7 693	75 171
2001	48 220	334	1 230	13 072	5 798	7 900	76 555
2002	48 515	334	1 240	13 848	5 893	8 113	77 943
2003	48 806	334	1 250	14 634	5 986	8 327	79 339
2004	49 081	334	1 260	15 431	6 079	8 555	80 740
2005	49 337	334	1 270	16 264	6 170	8 784	82 159
2006	49 559	334	1 280	17 080	6 256	9 033	83 542
2007	49 803	334	1 289	17 819	6 338	9 288	84 871
2008	49 921	334	1 298	18 508	6 416	9 560	86 036
2009	50 006	334	1 307	19 189	6 488	9 838	87 162
2010	50 048	334	1 316	19 851	6 555	10 148	88 252
2011	50 034	334	1 324	20 526	6 623	10 453	89 294
2012	49 958	334	1 333	21 222	6 692	10 772	90 312
2013	49 822	334	1 341	22 030	6 762	11 111	91 399
2014	49 640	334	1 350	22 879	6 828	11 475	92 505
2015	49 398	334	1 358	23 809	6 893	11 805	93 598
Cumulative 1996–2015	977 166	6 680	25 440	332 322	123 307	181 697	1 646 614

Note Figures from 1994 are BTCE estimates.

Sources BTCE 1995c, 1996c; BTCE estimates.

TABLE III.2 BASECASE DOMESTIC TRANSPORT EMISSIONS BY MODE

(thousand tonnes of CO_2 equivalent)

Year	Road	Rail	Air	Sea	Total
1971	35 114	3 126	1 992	3 040	43 270
1972	36 528	3 026	2 122	3 512	45 188
1973	37 968	2 977	2 296	3 778	47 020
1974	40 520	2 979	2 671	4 057	50 227
1975	42 986	3 120	2 914	3 544	52 564
1976	45 047	3 193	2 944	3 174	54 358
1977	47 265	3 188	3 035	3 763	57 250
1978	49 134	3 212	3 231	4 526	60 102
1979	51 140	3 242	3 186	3 843	61 411
1980	51 833	3 260	3 307	4 248	62 648
1981	52 433	3 316	3 292	4 223	63 265
1982	55 284	3 291	3 500	3 413	65 489
1983	54 301	3 107	3 399	3 380	64 186
1984	56 423	3 352	3 380	3 351	66 507
1985	59 136	3 550	3 458	3 040	69 183
1986	59 820	3 534	3 693	3 053	70 100
1987	60 279	3 646	3 838	3 183	70 947
1988	62 631	3 749	4 098	3 057	73 535
1989	64 228	3 739	4 063	2 812	74 843
1990	64 817	3 759	3 347	2 420	74 343
1991	63 252	3 739	4 085	2 029	73 105
1992	64 335	3 682	4 409	2 070	74 496
1993	65 552	3 646	4 618	1 763	75 579
1994	67 095	3 676	4 577	1 764	77 112
1995	68 242	3 749	4 499	1 775	78 264
1996	69 759	3 825	4 660	1 782	80 026
1997	71 272	3 895	4 826	1 781	81 774
1998	72 689	3 976	4 997	1 795	83 457
1999	74 019	4 046	5 181	1 794	85 041
2000	75 171	4 122	5 377	1 805	86 475
2001	76 555	4 197	5 580	1 819	88 151
2002	77 943	4 272	5 790	1 833	89 838
2003	79 339	4 347	6 007	1 816	91 508
2004	80 740	4 421	6 232	1 800	93 193
2005	82 159	4 495	6 464	1 785	94 903
2006	83 542	4 570	6 704	1 770	96 585
2007	84 871	4 643	6 952	1 759	98 226

Continued on next page

TABLE III.2 BASECASE DOMESTIC TRANSPORT EMISSIONS BY MODE (continued)

(thousand tonnes of CO_2 equivalent)

Year	*Road*	*Rail*	*Air*	*Sea*	*Total*
2008	86 036	4 717	7 209	1 748	99 710
2009	87 162	4 791	7 475	1 739	101 167
2010	88 252	4 864	7 749	1 731	102 597
2011	89 294	4 938	8 032	1 723	103 987
2012	90 312	5 011	8 325	1 717	105 366
2013	91 399	5 084	8 629	1 712	106 824
2014	92 505	5 158	8 943	1 708	108 314
2015	93 598	5 257	9 267	1 707	109 828
Cumulative 1996–2015	1 646 614	90 630	134 401	35 325	1 906 970

Note Figures from 1994 are BTCE estimates.

Notes
1. Figures include emissions from military transport. In 1993, military transport accounted for around 16 per cent of emissions from domestic air transport, 6 per cent for sea transport, and 0.2 per cent for land transport.
2. Figures do not include emisisons from off-road mobile equipment, such as tractors and forklifts.
3. Sea refers to commercial shipping, and does not include emissions from small craft (such as pleasure boats or fishing vessels).
4. With the exception of rail, figures refer solely to emissions from energy end-use. Rail estimates include emissions resulting from the generation of electricity for trains and trams. Inclusion of emissions due to the refining and distribution of petroleum fuels would increase the estimates for petroleum-fuelled modes by about 10 per cent. Exclusion of emissions from power stations providing electricity for electric traction would approximately halve the estimates given in the table for rail emissions.
5. Figures from 1994 are BTCE estimates.

Sources BTCE 1995c, 1996a; BTCE estimates.

TABLE III.3 BASECASE INTERNATIONAL TRANSPORT EMISSIONS BY MODE

(thousand tonnes of CO_2 equivalent)

Year	*Air*	*Sea*	*Total*
1971	1 034	4 672	5 706
1972	1 391	4 916	6 307
1973	1 645	5 900	7 546
1974	1 965	6 715	8 680
1975	2 169	5 974	8 143
1976	2 195	5 412	7 607
1977	2 259	5 822	8 081
1978	2 412	5 560	7 972
1979	2 374	5 292	7 666
1980	2 477	4 377	6 854
1981	2 468	4 342	6 810
1982	2 647	3 083	5 731
1983	2 577	3 223	5 800
1984	2 571	2 722	5 293
1985	2 895	2 691	5 586
1986	2 953	1 833	4 786
1987	3 118	1 943	5 062
1988	3 527	2 192	5 719
1989	4 072	2 485	6 557
1990	4 448	2 538	6 986
1991	4 627	2 296	6 923
1992	4 909	2 210	7 119
1993	5 306	2 209	7 515
1994	5 327	2 225	7 552
1995	5 518	2 306	7 824
1996	5 776	2 381	8 156
1997	6 045	2 438	8 483
1998	6 327	2 512	8 838
1999	6 647	2 573	9 220
2000	7 004	2 571	9 575
2001	7 382	2 561	9 943
2002	7 782	2 565	10 346
2003	8 204	2 558	10 763
2004	8 652	2 552	11 204
2005	9 121	2 554	11 675
2006	9 616	2 557	12 174
2007	10 141	2 557	12 698

Continued on next page

TABLE III.3 BASECASE INTERNATIONAL TRANSPORT EMISSIONS BY MODE (continued)

(thousand tonnes of CO_2 equivalent)

Year	*Air*	*Sea*	*Total*
2008	10 696	2 556	13 251
2009	11 283	2 555	13 838
2010	11 897	2 563	14 460
2011	12 546	2 571	15 116
2012	13 232	2 577	15 809
2013	13 958	2 583	16 540
2014	14 725	2 587	17 312
2015	15 550	2 591	18 141

Note 1. International refers to (end-use) emissions from bunker fuel uplifted in Australia by international transport.

2. Figures from 1994 are BTCE estimates.

Sources BTCE 1995c, 1996a; BTCE estimates.

TABLE III.4 BASECASE PASSENGER CAR EMISSION PROJECTIONS BY GAS TYPE

(thousand tonnes of gas)

Year	CO_2	*CO*	NO_x	CH_4	N_20	*NMVOCs*	CO_2 *equivalent*
1991	33 334	3 085	208.3	16.6	1.5	502.6	42 978
1992	33 804	3 079	211.7	16.2	1.6	493.0	43 429
1993	34 252	3 039	211.9	15.6	1.7	480.3	43 769
1994	35 198	3 030	215.2	15.3	1.9	474.3	44 733
1995	35 742	2 978	215.6	14.8	2.1	463.8	45 185
1996	36 572	2 934	215.5	14.3	2.3	463.0	46 009
1997	37 244	2 872	214.7	13.7	2.4	453.2	46 566
1998	37 865	2 803	213.6	13.2	2.6	442.3	47 057
1999	38 424	2 739	212.5	12.7	2.7	432.0	47 493
2000	38 941	2 675	211.4	12.3	2.8	422.5	47 893
2001	39 381	2 609	211.2	11.9	3.0	413.0	48 220
2002	39 771	2 555	211.2	11.4	3.1	404.9	48 515
2003	40 140	2 506	211.2	11.1	3.2	398.0	48 806
2004	40 484	2 461	211.1	10.9	3.3	391.9	49 081
2005	40 804	2 418	211.0	10.7	3.4	386.4	49 337
2006	41 079	2 384	209.7	10.5	3.4	382.5	49 559
2007	41 296	2 368	208.7	10.0	3.7	380.8	49 803
2008	41 460	2 342	207.4	10.0	3.7	378.2	49 921
2009	41 575	2 323	206.2	10.1	3.7	376.6	50 006
2010	41 633	2 309	205.0	10.2	3.8	376.0	50 048
2011	41 634	2 290	204.9	10.4	3.8	374.8	50 034
2012	41 578	2 270	204.9	10.7	3.8	373.3	49 958
2013	41 461	2 252	205.1	10.7	3.8	372.0	49 822
2014	41 286	2 236	205.4	11.2	3.9	370.7	49 640
2015	41 050	2 219	205.5	11.9	3.9	369.5	49 398
Cumulative 1996–2015							977 167

Note CO_2 emission figures are estimated by assuming that the total carbon content of the fuel is converted to CO_2 during fuel combustion, even though a portion of the carbon in the fuel is released as CO and volatile organic compunds which eventually oxidise to CO_2 in the atmosphere. The GWPs used to calculate CO_2 equivalent emissions (given in appendix IV) have been adjusted to avoid double counting the fuel carbon emitted. CO_2 equivalent emissions are calculated by summing the mass of emissions multiplied by the respective GWP.

Sources BTCE 1995c, 1996a; BTCE estimates.

TABLE III.5 BASECASE ROAD FREIGHT VEHICLE EMISSION PROJECTIONS BY GAS TYPE

(thousand tonnes of gas)

Year	CO_2	*CO*	NO_x	CH_4	N_2O	*NMVOCs*	CO_2 *equivalent*
1991	16 589	527.0	120.9	3.12	0.47	58.8	18 781
1992	17 222	533.0	121.7	3.03	0.49	58.0	19 424
1993	18 004	554.0	127.2	3.15	0.51	60.5	20 300
1994	18 518	580.0	128.2	3.27	0.52	62.3	20 869
1995	19 124	603.0	132.1	3.39	0.54	64.3	21 554
1996	19 710	621.0	137.4	3.60	0.55	67.9	22 238
1997	20 526	660.3	143.1	3.82	0.58	71.6	23 183
1998	21 308	701.8	148.8	4.06	0.61	75.6	24 099
1999	22 048	746.3	155.0	4.32	0.64	79.8	24 982
2000	22 635	794.8	161.6	4.59	0.67	84.3	25 723
2001	23 530	840.9	168.3	4.86	0.70	88.7	26 770
2002	24 453	889.4	175.4	5.14	0.73	93.4	27 853
2003	25 383	939.1	182.7	5.43	0.77	98.1	28 948
2004	26 329	990.2	190.3	5.73	0.81	103.1	30 064
2005	27 303	1 044.2	198.2	6.04	0.84	108.3	31 218
2006	28 271	1 099.2	206.5	6.36	0.88	113.6	32 369
2007	29 167	1 151.8	214.7	6.66	0.92	118.7	33 444
2008	30 027	1 203.9	223.0	6.96	0.96	123.8	34 483
2009	30 873	1 258.0	231.6	7.28	1.00	129.1	35 515
2010	31 719	1 313.9	240.6	7.60	1.04	134.6	36 554
2011	32 567	1 371.9	249.9	7.94	1.08	140.3	37 601
2012	33 443	1 433.1	259.6	8.30	1.13	146.2	38 686
2013	34 424	1 502.7	270.3	8.70	1.18	153.0	39 902
2014	35 454	1 576.7	281.6	9.13	1.23	160.2	41 182
2015	36 517	1 656.2	293.2	9.59	1.29	167.8	42 507
Cumulative 1996–2015							637 322

Notes 1. CO_2 emission figures are estimated by assuming that the total carbon content of the fuel is converted to CO_2 during fuel combustion, even though a portion of the carbon in the fuel is released as CO and volatile organic compunds which eventually oxidise to CO_2 in the atmosphere. The global warming potentials (GWPs) used to calculate CO_2 equivalent emissions (given in appendix IV) have been adjusted to avoid double counting the fuel carbon emitted. CO_2 equivalent emissions are calculated by summing the mass of emissions multiplied by the respective GWP.

2. Road freight vehicles include light commercial vehicles, rigid trucks and articulated trucks.

Sources BTCE 1995c, 1996c; BTCE estimates.

TABLE III.6 BASECASE RAIL EMISSION PROJECTIONS BY GAS TYPE

(thousand tonnes of gas)

Year	*CO_2*	*CO*	*NO_x*	*CH_4*	*N_20*	*NMVOCs*	*CO_2 equivalent*
1991	3 296	14.45	47.59	0.16	0.06	3.04	3 739
1992	3 251	13.99	46.30	0.15	0.06	2.94	3 682
1993	3 223	13.70	45.47	0.15	0.06	2.88	3 646
1994	3 255	13.60	45.35	0.15	0.06	2.85	3 676
1995	3 320	13.78	46.05	0.15	0.06	2.89	3 749
1996	3 390	13.97	46.79	0.15	0.06	2.93	3 825
1997	3 453	14.13	47.44	0.15	0.06	2.96	3 895
1998	3 528	14.32	48.22	0.16	0.06	3.00	3 976
1999	3 592	14.48	48.85	0.16	0.06	3.03	4 046
2000	3 661	14.66	49.57	0.16	0.07	3.07	4 122
2001	3 730	14.84	50.29	0.16	0.07	3.10	4 197
2002	3 798	15.02	51.01	0.16	0.07	3.14	4 272
2003	3 866	15.20	51.74	0.17	0.07	3.18	4 347
2004	3 934	15.38	52.47	0.17	0.07	3.21	4 421
2005	4 001	15.57	53.21	0.17	0.07	3.25	4 495
2006	4 068	15.75	53.95	0.17	0.07	3.29	4 570
2007	4 135	15.94	54.69	0.18	0.07	3.33	4 643
2008	4 202	16.13	55.45	0.18	0.08	3.36	4 717
2009	4 269	16.32	56.21	0.18	0.08	3.40	4 791
2010	4 335	16.52	56.98	0.18	0.08	3.44	4 864
2011	4 401	16.72	57.76	0.19	0.08	3.48	4 938
2012	4 467	16.92	58.55	0.19	0.08	3.52	5 011
2013	4 533	17.12	59.35	0.19	0.08	3.56	5 084
2014	4 599	17.33	60.16	0.19	0.08	3.60	5 158
2015	4 689	17.58	61.08	0.20	0.08	3.65	5 257

Notes 1. Rail estimates include emissions resulting from the generation of electricity for trains and trams.

2. CO_2 emission figures are estimated by assuming that the total carbon content of the fuel is converted to CO_2 during fuel combustion, even though a portion of the carbon in the fuel is released as CO and volatile organic compunds which eventually oxidise to CO_2 in the atmosphere. The global warming potentials (GWPs) used to calculate CO_2 equivalent emissions (given in appendix IV) have been adjusted to avoid double counting the fuel carbon emitted. CO_2 equivalent emissions are calculated by summing the mass of emissions multiplied by the respective GWP.

Sources BTCE 1995c; BTCE estimates.

TABLE III.7 BASECASE COASTAL SHIPPING EMISSION PROJECTIONS BY GAS TYPE

(thousand tonnes of gas)

Year	*CO_2*	*CO*	*NO_x*	*CH_4*	*N_20*	*NMVOCs*	*CO_2 equivalent*
1991	1 704	2.60	37.13	0.071	0.041	1.33	2 029
1992	1 739	3.06	37.58	0.074	0.042	1.39	2 070
1993	1 490	2.63	31.02	0.062	0.035	1.15	1 763
1994	1 469	2.41	33.73	0.063	0.037	1.23	1 764
1995	1 478	2.42	33.94	0.064	0.037	1.24	1 775
1996	1 483	2.43	34.06	0.064	0.037	1.24	1 782
1997	1 483	2.43	34.05	0.064	0.037	1.24	1 781
1998	1 494	2.45	34.31	0.064	0.038	1.25	1 795
1999	1 494	2.45	34.30	0.065	0.038	1.25	1 794
2000	1 503	2.46	34.51	0.065	0.038	1.26	1 805
2001	1 514	2.48	34.76	0.065	0.038	1.27	1 819
2002	1 526	2.50	35.04	0.066	0.038	1.28	1 833
2003	1 512	2.48	34.71	0.065	0.038	1.27	1 816
2004	1 498	2.46	34.40	0.065	0.038	1.25	1 800
2005	1 486	2.44	34.11	0.064	0.037	1.24	1 785
2006	1 474	2.42	33.84	0.064	0.037	1.23	1 770
2007	1 464	2.40	33.36	0.063	0.037	1.23	1 759
2008	1 455	2.39	33.41	0.063	0.037	1.22	1 748
2009	1 448	2.37	33.24	0.062	0.036	1.21	1 739
2010	1 441	2.36	33.10	0.062	0.036	1.21	1 731
2011	1 435	2.35	32.94	0.062	0.036	1.20	1 723
2012	1 430	2.34	32.83	0.062	0.036	1.20	1 717
2013	1 425	2.34	32.73	0.061	0.036	1.19	1 712
2014	1 422	2.33	32.66	0.061	0.036	1.19	1 708
2015	1 421	2.33	32.62	0.061	0.036	1.19	1 707

Note CO_2 emission figures are estimated by assuming that the total carbon content of the fuel is converted to CO_2 during fuel combustion, even though a portion of the carbon in the fuel is released as CO and volatile organic compunds which eventually oxidise to CO_2 in the atmosphere. The global warming potentials (GWPs) used to calculate CO_2 equivalent emissions (given in appendix IV) have been adjusted to avoid double counting the fuel carbon emitted. CO_2 equivalent emissions are calculated by summing the mass of emissions multiplied by the respective GWP.

Sources BTCE 1995c; BTCE estimates.

TABLE III.8 BASECASE DOMESTIC AVIATION EMISSION PROJECTIONS BY GAS TYPE

(thousand tonnes of gas)

Year	CO_2	*CO*	NO_x	CH_4	N_20	*NMVOCs*	CO_2 *equivalent*
1991	3 825	83.98	14.55	0.26	0.11	2.33	4 085
1992	4 140	79.80	15.85	0.25	0.12	2.27	4 409
1993	4 335	84.57	16.58	0.27	0.12	2.40	4 618
1994	4 295	85.66	16.41	0.27	0.12	2.42	4 577
1995	4 218	86.71	16.10	0.27	0.12	2.43	4 499
1996	4 372	88.02	16.70	0.28	0.13	2.48	4 660
1997	4 529	89.34	17.32	0.28	0.13	2.53	4 826
1998	4 692	90.67	17.95	0.29	0.13	2.58	4 997
1999	4 867	92.01	18.64	0.29	0.14	2.63	5 181
2000	5 054	93.36	19.37	0.30	0.15	2.68	5 377
2001	5 247	94.73	20.14	0.30	0.15	2.74	5 580
2002	5 447	96.09	20.92	0.31	0.16	2.79	5 790
2003	5 654	97.47	21.74	0.32	0.16	2.85	6 007
2004	5 868	98.85	22.58	0.32	0.17	2.90	6 232
2005	6 088	100.25	23.45	0.33	0.18	2.96	6 464
2006	6 317	101.65	24.35	0.33	0.18	3.02	6 704
2007	6 553	103.06	25.28	0.34	0.19	3.08	6 952
2008	6 798	104.49	26.25	0.35	0.20	3.14	7 209
2009	7 052	105.92	27.25	0.36	0.20	3.20	7 475
2010	7 313	107.36	28.28	0.36	0.21	3.27	7 749
2011	7 583	108.81	29.34	0.37	0.22	3.33	8 032
2012	7 863	110.27	30.44	0.38	0.23	3.40	8 325
2013	8 152	111.74	31.59	0.38	0.24	3.47	8 629
2014	8 451	113.23	32.77	0.39	0.24	3.54	8 943
2015	8 761	114.72	33.99	0.40	0.25	3.61	9 267

Note 1. CO_2 emission figures are estimated by assuming that the total carbon content of the fuel is converted to CO_2 during fuel combustion, even though a portion of the carbon in the fuel is released as CO and volatile organic compunds which eventually oxidise to CO_2 in the atmosphere. The global warming potentials (GWPs) used to calculate CO_2 equivalent emissions (given in appendix IV) have been adjusted to avoid double counting the fuel carbon emitted. CO_2 equivalent emissions are calculated by summing the mass of emissions multiplied by the respective GWP. Includes emissions from both avtur and avgas.

2. Includes emissions from both avtur and avgas.

Sources BTCE 1995c; BTCE estimates.

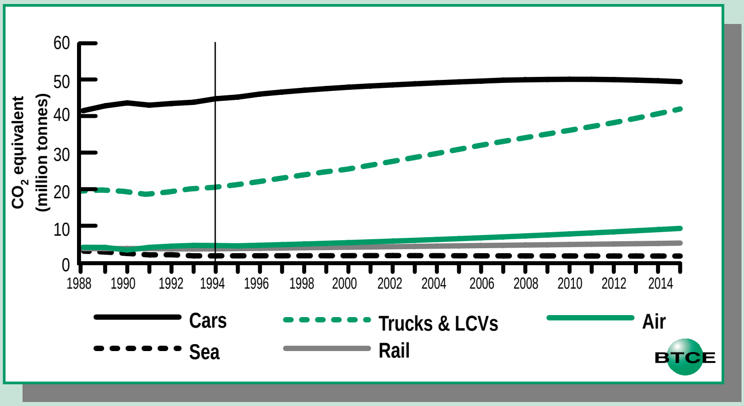
TABLE III.9 BASECASE PASSENGER CAR EMISSION PROJECTIONS BY SECTOR

(thousand tonnes of CO_2 equivalent)

Year	*Urban*	*Non-urban*
1991	31 245	11 733
1992	31 584	11 845
1993	31 837	11 932
1994	32 545	12 188
1995	32 882	12 303
1996	33 646	12 363
1997	34 217	12 349
1998	34 742	12 316
1999	35 231	12 262
2000	35 699	12 194
2001	36 116	12 105
2002	36 512	12 003
2003	36 907	11 899
2004	37 293	11 788
2005	37 667	11 671
2006	38 016	11 543
2007	38 388	11 415
2008	38 658	11 263
2009	38 902	11 104
2010	39 111	10 937
2011	39 275	10 758
2012	39 392	10 566
2013	39 460	10 361
2014	39 490	10 149
2015	39 470	9 928

Sources BTCE 1995c, 1996a; BTCE estimates.

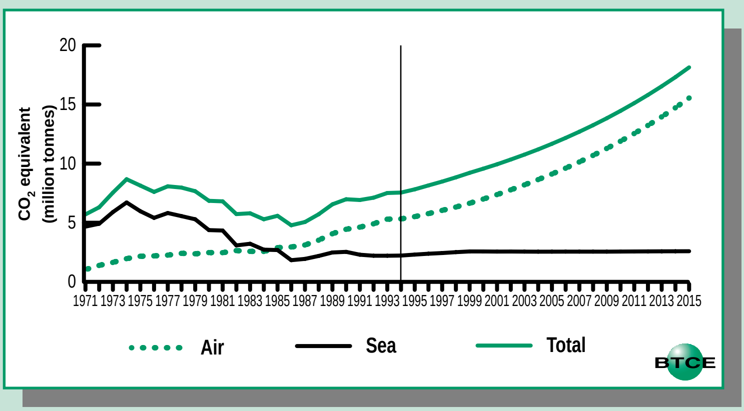
FIGURE III.1 CO_2 EQUIVALENT EMISSIONS FROM AUSTRALIAN DOMESTIC TRANSPORT



Note Figures from 1994 onwards are BTCE projections.

Sources BTCE 1995c, 1996a, 1996e; BTCE estimates.

FIGURE III.2 CO_2 EQUIVALENT EMISSIONS FROM FUEL UPLIFTED IN AUSTRALIA BY INTERNATIONAL TRANSPORT



Note Figures from 1994 onwards are BTCE projections.

Sources BTCE 1995, 1996; BTCE estimates.

APPENDIX IV CONVERSION FACTORS FOR GREENHOUSE GASES

GLOBAL WARMING POTENTIALS

Carbon dioxide is the major greenhouse gas emission from human activities, but the contributions of other gases are important, even in the transport sector.

The warming effect of a greenhouse gas depends on its atmospheric concentration and reactivity, infrared absorption capability, and average residency time in the atmosphere. These factors vary considerably among gases. To represent the total greenhouse effect of emissions of several different gases from an activity, or to compare the greenhouse (or radiative forcing) effect of emissions of different gases, their emissions are stated in terms of CO_2 equivalents. The relative greenhouse effect of various greenhouse gases can be determined on the basis of the global warming potential (GWP) for each gas.

The GWP is an index defined as the cumulative radiative forcing between the present and some chosen time horizon caused by a unit mass of gas emitted now, expressed relative to that for some reference gas such as carbon dioxide (IPCC 1996, p. 21). The future global warming commitment of a greenhouse gas over a chosen time horizon can be estimated by multiplying the appropriate GWP by the amount of gas emitted.

Representative GWP values have been estimated for the main greenhouse gases by the Intergovernmental Panel on Climate Change (IPCC). Due to the varying lifetimes of greenhouse gases, GWP figures depend on the assumed time period over which the effects of emissions are considered. The IPCC (1996, 1994, 1992, 1990) has estimated GWP factors which range over various time horizons, including 20 years, 100 years and 500 years. Estimated values for the direct GWP components given in IPCC (1994, p. 28) are presented in table IV.1. Indirect GWP values were reported in IPCC 1990, and these are also presented in table IV.1. Due to the present incomplete understanding of the complex chemical processes involved in the indirect effects, numerical values for indirect GWPs were not given in the more recent IPCC reports.

Derivation of GWPs requires knowledge of the fate of the emitted gas and the radiative forcing due to the amount remaining in the atmosphere. Although the GWPs are quoted in table IV.1 as single values, the typical uncertainty is ±35 per cent, not including the uncertainty in the carbon dioxide reference (IPCC 1996, p. 21).

The set of GWPs given in table IV.1 does not explicitly represent the current IPCC position (which is periodically revised), but is an indicative scenario for global warming based on various IPCC results. Although the IPCC is reasonably confident that the GWP values for direct effects are of the right order, the current uncertainty surrounding the indirect effects hampers quantitative analysis required to compare alternative fuels.

TABLE IV.1 GLOBAL WARMING POTENTIALS OF ATMOSPHERIC GASES RELATIVE TO CO_2, FOR DIFFERENT TIME HORIZONS

Type of greenhouse gas	*Atmospheric concentration in 1992 (parts per million by volume)*	*Estimated atmospheric lifetime (years)*	*GWP over time horizon (years)*		
			20	*100*	*500*
Direct					
CO_2	355	50–200	1	1	1
CH_4[a]	1.7	9–15	62	24.5	7.5
N_2O	0.3	120	290	320	180
HFC-134a[b]	0.0	14.6	3 400	1 300	420
Indirect (ozone precursors)[c]					
CO	0.1–40	0.4	5	1	0.0
NO_X	0.01–0.2	<1	30	8	3
NMVOCs	0.2–0.5	<1	28	8	3

a. The methane GWP includes its direct effect and indirect effects due to the production of tropospheric ozone and stratospheric water vapour.

b. HFC-134a is the main chlorofluorocarbon replacement being used in new vehicle air-conditioners.

c. Indirect GWPs include effects due to the production of troposheric ozone, but do not include effects due to the eventual conversion to CO_2 in the atmosphere.

Sources IPCC 1990, 1992, 1994, 1996; IEA 1993.

Rather than omit such analysis, the BTCE has used the 100-year GWP scenario given in table IV.1, on the understanding that the results derived need to be suitably qualified.

Direct GWP values given in table IV.1 have been revised slightly by the IPCC since the release of BTCE's long-term projections (1995c, p. 144). For example, IPCC (1996, p. 22) gives the 100-year GWP value for methane as 21, revised from 24.5 since 1994. Because of the relatively low amount of methane emissions from the transport sector, the use of 24.5 here instead of 21 as the GWP for methane is not considered to materially affect the results obtained in this Report. Any differences would be swamped by other uncertainties, including scientific uncertainties in the GWPs themselves.

FUEL EMISSION FACTORS

Greenhouse gas emissions from mobile sources consist of the gaseous products of engine fuel combustion (exhaust emissions) and gas leakage from vehicles (fugitive emissions). Estimation of emissions is complex because emission levels depend on a large number of factors such as class of vehicle, type of pollution control equipment fitted, type of fuel consumed, etc.

Calculation of non-CO_2 greenhouse gas emissions from the combustion and evaporation of fuels in mobile engines is carried out by converting activity data (either fuel consumption or distance travelled) to an emission estimate through multiplication by a conversion rate or emission factor. Emission factor units are expressed as grams of gas emitted per megajoule of energy used (g/MJ) or grams emitted per vehicle-kilometre travelled (g/km).

Carbon dioxide emissions from the combustion of fuels are estimated by converting energy consumption (MJ/litre) for each mobile engine type to an amount of CO_2 through multiplication by an emission factor (g/MJ) and an oxidation factor. The oxidation factor represents the proportion of fuel oxidised during combustion. One minus the factor represents the proportion of fuel that is converted into solid products such as soot.

Table IV.2 provides information on carbon dioxide emission factors, oxidation, and energy densities. Average factors used for aircraft emissions are given in table IV.3, and those for rail in table IV.4. Further detail on estimating emissions from the transport sector are given in BTCE (1995c, appendix V).

TABLE IV.2 CO_2 EMISSION FACTORS AND ENERGY DENSITIES BY FUEL TYPE

Fuel type	*Proportion of fuel oxidised*	*CO_2 emission factor (g/MJ)*	*Energy density (MJ/L)*
Automotive gasoline	0.99	66.0	34.2
Automotive diesel oil	0.99	69.7	38.6
Liquefied petroleum gas	0.99	59.4	25.7
Aviation gasoline	0.99	68.0	33.1
Aviation turbine fuel	0.99	67.8	36.8
Industrial diesel fuel	0.99	70.2	39.6
Fuel oil	0.99	73.3	40.8
Natural gas	1.00	51.3	..
Black coal	0.99	90.0	..

.. Not applicable

Notes
1. Values are expressed in GCV (gross calorific value) terms.
2. Figures for automotive gasoline refer to both leaded and unleaded forms.
3. Coal energy densities vary from mine to mine. New South Wales black coal has an average energy density of about 23 MJ/kg. Victorian brown coal has an energy density of around 10 MJ/kg. The energy density of natural gas is about 39 MJ/cubic metre.

Source BTCE 1995c, p. 181.

TABLE IV.3 AVERAGE AVIATION EMISSION FACTORS

(grams per megajoule of fuel)

Gas	*Avgas*	*Domestic avtur*	*International avtur*
CO_2	68.0	67.8	67.8
NO_x	0.076	0.27	0.26
CH_4	0.057	0.0011	0.0004
NMVOCs	0.513	0.01	0.004
CO	22.8	0.079	0.05
N_2O	0.0009	0.002	0.002

Source BTCE 1995c, p. 63.

TABLE IV.4 RAIL EMISSION FACTORS

(gigagrams per megajoule)

Gas	*Electricity*[a]	*ADO*	*IDF*	*Black coal*
CO_2	273.0	69.70	70.20	90.00
NO_x	2.129	1.710	1.710	0.300
CH_4	0.016	0.006	0.006	0.002
NMVOCs	..	0.124	0.124	..
CO	0.043	0.580	0.580	0.088
N_2O	0.002	0.002	0.002	0.001

.. not applicable (assumed negligible)

ADO automotive diesel oil

IDF industrial diesel fuel

a. These factors are for the year 1992-93. It is assumed that the electricity emission factors will have declined by 2 per cent by the year 2014-15.

Note Emission factors for electricity use include the combustion of primary fuels by electric power stations; all other conversion factors refer solely to energy end-use.

Source BTCE 1995c, p. 60.

Estimates of CO_2 emissions are based on the assumption of full carbon combustion. That is, the total carbon content of the fuel is accounted for as CO_2 emissions, even though a portion of the carbon in the fuel is released as CH_4, CO and NMVOC emissions under actual engine operating conditions. The Intergovernmental Panel on Climate Change (IPCC/OECD 1994) has established the standard that CO_2 emissions be reported as if all the carbon which is oxidised produces CO_2. As well as making the estimation of CO_2 emissions more straightforward, the main reason is that carbon emitted as CH_4, CO or NMVOCs eventually converts to CO_2 in the atmosphere. The conversion occurs over a relatively short period compared to the lifetime of CO_2 in the atmosphere (greater than 100 years).

To derive an estimate of actual CO_2 emissions for a given year (for example, as an input to a detailed atmospheric model), the carbon contained in the CH_4, CO and NMVOC emissions should be subtracted from the CO_2 emissions. To avoid slight double counting of carbon when summing across emission species (to calculate total CO_2 equivalent emissions), the effects of the full carbon combustion methodology are taken into account in the default GWPs in table IV.1. That is, CO_2 equivalent emissions are calculated in this Report by summing the mass of emissions multiplied by the respective GWP across all the gases.

APPENDIX V HIERARCHICAL MULTINOMIAL LOGIT MODELS OF CONSUMER CHOICE AND THE ITS/BTCE MODEL

The ITS/BTCE model of urban household travel behaviour is a hierarchical multinomial logit model of consumer travel behaviour based on a random-utility discrete-choice model of consumer preferences.

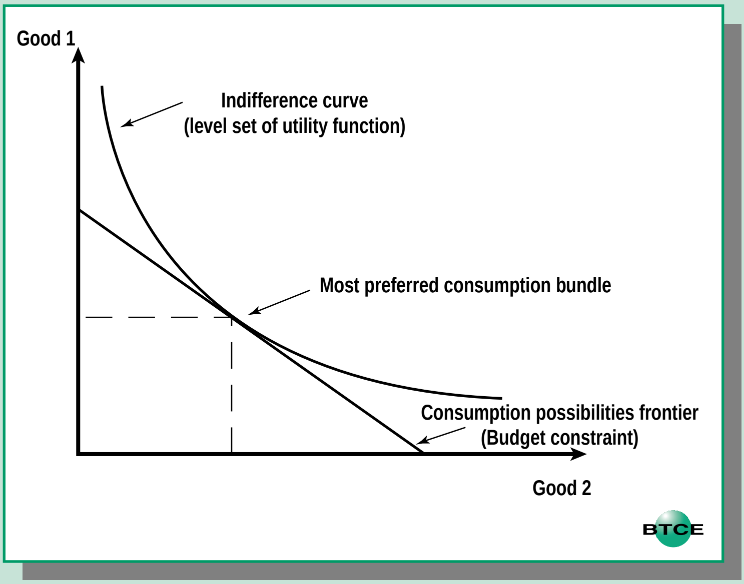
DISCRETE-CHOICE MODELS

In standard consumer theory households choose between amounts of continuously divisible commodities. They have utility functions, which depend on the amount that they consume and describe their set of preferences. Subject to a budget constraint, consumers try to maximise their utility. The consumer's budget constraint defines a consumption possibility frontier, which is a line (or plane or hyperplane) on a graph that has the amounts of different commodities consumed on the various axes. The maximum utility (or most preferred combination) is found at a point where an indifference curve (or a level set of the utility function) is tangential to the consumption possibilities frontier (figure V.1).

If the commodities were not divisible, or if the household was only able to choose between a finite set of fixed bundles of commodities, standard consumer theory can still be applied (Varian 1992, pp. 44, 109, 244). The set of possible consumption bundles would be points on the graph in 'commodity space', and the household would choose the option that had the highest utility value (that is, was on the highest indifference curve).

The hedonic theory of discrete choices is similar to the choice of a fixed bundle of commodities. Each commodity or combination of goods has a number of *attributes*, and can be represented as a point in a graph that has the different attributes on the axes. For example, cars might have fuel

FIGURE V.1 STANDARD TWO-GOOD CONSUMER THEORY DIAGRAM



Source BTCE estimates.

economy and passenger room as two attributes. Each brand and model could be graphed as a point in 'economy–roominess space'. Each consumer has a set of preferences (or a utility function) for economy and roominess. Consumers' indifference curves could be drawn on the graph of economy and roominess. Consumers' choices of brand and model could then be predicted just as for a choice between bundles of commodities.

Commodities can possess more than two attributes, just as there can be more than two commodities in standard consumer theory. For example, cars can be represented in terms of fuel economy, passenger room and colour. The diagrams become hard to draw, but the behavioural model and its results are easy to generalise.

Suppose that a discrete-choice model is applied to a large population, where different households have somewhat different utility functions. Also suppose that the cost of each option or bundle of commodities is a factor in its utility. Then a hedonic choice model can produce a fairly smooth market demand curve for each option: the number of consumers who choose an option will vary fairly smoothly with its price.

RANDOM UTILITY MODELS

In random utility models consumers choose between options as in hedonic choice theory. The utility derived by consumer *i* associated with each option *j*, U_{ij}, contains a systematic component V_{ij} (which is defined by a set of observed attributes each weighted by their contribution to overall utility of the alternative), plus an unobservable component ε_{ij} (which can be treated as random) shown in equation (V.1).

$$U_{ij} = V_{ij} + \varepsilon_{ij} \tag{V.1}$$

The random component ε_{ij} can represent any (or a combination) of the following:

- the value of attributes that matter but are not included in the model;
- the influence of variable factors (such as weather) on utility;
- differences of taste between different consumers.

In the last case, the utility functions of an individual consumer can be non-random, but the utility of a *randomly selected individual* will be randomly distributed around a population mean utility. If the utilities of various options depend on the age, sex, income, or cultural background of the consumer the random components will not be independent.

Because of the random component, it will be impossible to predict a (randomly selected) consumer's choice. But the distribution of the random component of each utility function may be known, or a particular distribution can be assumed. Assuming a distribution for the random component of utility allows empirical estimation of discrete-choice behaviour.

The derivation of most actual random utility models assumes that the random components of utility in all options are independent. Therefore the random component cannot include variation in preferences that occur because of characteristics of the consumer that affect preferences in a systematic way, such as age, sex, income, family situation, or cultural background. To model a population that varies in these characteristics it is necessary to construct and/or estimate separate models for each relevant socioeconomic category of consumers.

For a large population, the probability that a randomly selected consumer will prefer each option is approximately the proportion of the total population that will choose that option. So a random utility model can predict non-random behaviour for large populations.

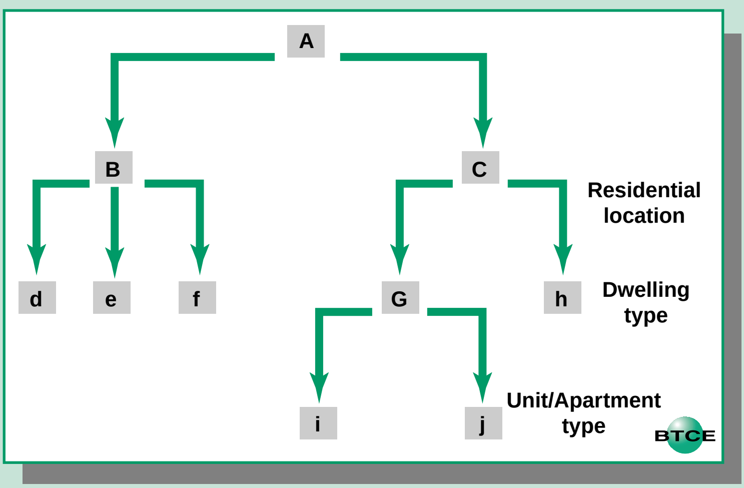
HIERARCHICAL DISCRETE-CHOICE MODELS

A hierarchical discrete-choice model represents a choice from among a large number of options as a number of simpler choices between clusters of options, ending in a choice of a single option from a small cluster.

Figure V.2 shows a hierarchical choice model with six options. The options are labelled with lower-case letters, and the clusters are labelled with upper-case letters. Cluster A consists of a simple choice between cluster B and cluster C. Cluster B consists of a choice among options d, e and f. (Because there are more than two options, this is called a multinomial choice.) Cluster C consists of a (simple) choice between a cluster (cluster G) and an option (option h).

Consider the hierarchical choice represented in figure V.2. *If* the consumer were to choose cluster B, he or she would then choose d, e or f, whichever happened to have the highest utility value. So the utility value of cluster B is the maximum out of the utility values of options d, e, and f. For the same reason, the utility value of cluster G is the maximum out of the utility values of options i and j. Likewise, the utility value of cluster C is the maximum out of the utility values of option h and cluster G.

FIGURE V.2 STRUCTURE OF A HYPOTHETICAL HIERARCHICAL CHOICE MODEL



Source BTCE estimates.

Essentially, a consumer modelled by this hierarchical choice will choose d, e, f, h, i or j. If this were a non-random hedonic choice, the consumer would simply choose the option with the highest utility value. The intermediate 'options' B, C, and G are not observed, and may be purely hypothetical.

Hierarchical choice models simplify modelling and estimation. Use of a hierarchical model does not necessarily suggest that actual consumers make their choices in the order that the model does, that they recognise the clusters that the model does, or even that they make choices in a hierarchical fashion.

In interpreting a hierarchical choice model it is sometimes easiest to think of consumers working their way down the tree of choices in the obvious fashion. Sometimes it is easiest to think of consumers making conditional choices at the bottom clusters of the tree, and then working their way up by comparing, at each higher cluster, the values of the options and the conditional optimums of the lower-down choices. Sometimes neither seems realistic, and it is necessary to see the hierarchical model as a compact or easy to estimate way of describing a choice from a vast array of options.

For example, figure V.2 could be thought of as a model in which the top level is a choice of which suburb a consumer will live in, and the next level down represents a choice of what type of dwelling to live in. This could represent a consumer first choosing a suburb, then choosing a particular dwelling (which falls into a dwelling type). It could represent a consumer making a conditional choice such as 'the best option in suburb B is such-and-such a house (which is type e)' for each suburb, and then comparing the conditional choices to choose a suburb. It could just be a way to estimate and compactly describe a model in which consumers evaluate all the options available, and choose their favourite.

A hierarchical model can also be thought of in terms of a summary of an array of probabilities. For example, the difference between choosing location 'before' dwelling type or vice versa is the same as choosing a column before a row or vice versa, using column or row total probabilities.

A model may have been fitted to observed data using statistical techniques. If the modeller was using a specific type of model (such as hierarchical logit), one type of tree (such as placing the location type choice 'before' the dwelling type choice) may have given a better fit to the data than its obvious rivals. In such a case the structure of the tree is important, but it does not obviously represent an ordered choice.

HIERARCHICAL RANDOM UTILITY MODELS

Suppose that there were a random component in the utility values of each of the options d, e, f, h, i and j in figure V.2. Suppose also that we know the distributions of all the random components. Then, if the distributions are mathematically tractable, it is possible to calculate the expected value of G. This is the expected maximum of the value of i and the value of j, and is called the *Inclusive Value* of the cluster. It represents the expected maximum utility of the choice between i and j conditional on the choice of cluster G.

If the distributions are tractable, it is also possible to identify the *distribution* of the value of G. From the distribution of G the chance that the utility value of cluster G is greater than the utility value of option h can be estimated. If the distributions are tractable the Inclusive Value of cluster C and its distribution can be estimated. The same can be done for cluster B. Similarly, the probability that the value of cluster B will exceed the value of cluster C can be worked out. This will be the probability that a randomly selected consumer will choose cluster B in preference to cluster C.

Provided that all the distributions are tractable, the Inclusive Value of any cluster and its distribution can be estimated. This can be done by working up from the bottom of the tree. The approach can be applied to a tree of any shape.

The essence of the procedure is that the *Inclusive Value* (expected value) of any cluster and the *distribution of the value* of that cluster encode the necessary information about all the possible options in the cluster. This information is passed up and used to calculate the Inclusive Value (and the distribution of the value) of the next cluster up the tree.

Inclusive Values are calculated by starting at the bottom of the tree and working upwards. Probabilities are calculated in the reverse order starting from the top once the Inclusive Values have been found. The probability of a consumer choosing an option (or sub-cluster) in a given cluster is the probability that they will choose the cluster, times the conditional probability that they will choose the option (or sub-cluster), given that they choose the cluster.

HIERARCHICAL LOGIT MODELS

The multinomial logit model is not the only model for constructing a hierarchical random utility model: the multinomial probit model with a factorial structure can have the same pattern of choice, but the multinomial logit model is more easily estimated (McFadden 1984, p. 1426). To derive the multinomial logit model it is assumed:

1. That the random components in all the utility functions have a Weibull distribution (also called the 'double-exponential' or 'extreme value type I' distribution), which has the probability density function (Maddala 1983, p. 60):

$$f(x) = e^{-x-e^{-x}}, \qquad -\infty \leq x < \infty \tag{V.2}$$

2. That the random components in the utility functions of the different options are all independent (and therefore cannot include socioeconomic indicators such as wealth, income, racial, sex, age, or cultural effects—these effects are captured by including individual specific socioeconomic indicators in the systematic utility component).
3. That, within any cluster, the standard deviations of all the random components are the same. (To allow the standard deviations in different clusters to be different, different units of utility are used in different clusters, and an appropriate scaling factor is applied to each Inclusive Value when it is used at the next level up).

These assumptions produce a model with the following properties:

- Each cluster of options is a familiar 'multinomial logit model'.
- The probability of choosing a given option within a cluster has a fairly simple formula.
- The Inclusive Value of a cluster of options has a fairly simple formula.
- The value of a cluster itself has a Weibull distribution. This means that the same type of model is used at all levels of the tree, and can combine a mixture of options and clusters into a single cluster.

On the other hand, the hierarchical logit model has the following weaknesses:

- It forces the assumption of a particular distribution for the random components of each utility, which in turn implies a certain form of demand curve that may place restrictions on allowable patterns of demand.

- It forces the assumption that the random components of utility are all independent.
- It forces the assumption that the random components of utility of each option within a cluster have the same standard deviation. Scaling factors between choices and their sub-clusters alleviate the resulting difficulties, but cross-price and cross-quantity effects are severely constrained.
- It has a property called 'independence of irrelevant alternatives' that causes difficulties when adding new options to an existing logit model. The problem arises because the log-odds ratio (the logarithm of the probability of choosing option i divided by the probability of choosing option j) between two specific choices is a function only of the attributes of those two choices, remaining constant as we add more options. For example, consider a commuter who chooses between taking a red bus or driving by car. Suppose another option, a blue bus, is added to the choice set. In the logit model the relative probability of taking the red bus or driving by car is unchanged. The logit model will predict that blue bus passengers switched from the red bus and car travel in equal proportions, but it seems more reasonable to assume that most of the blue bus passengers would have switched from travelling on the red bus, an almost perfect substitute.

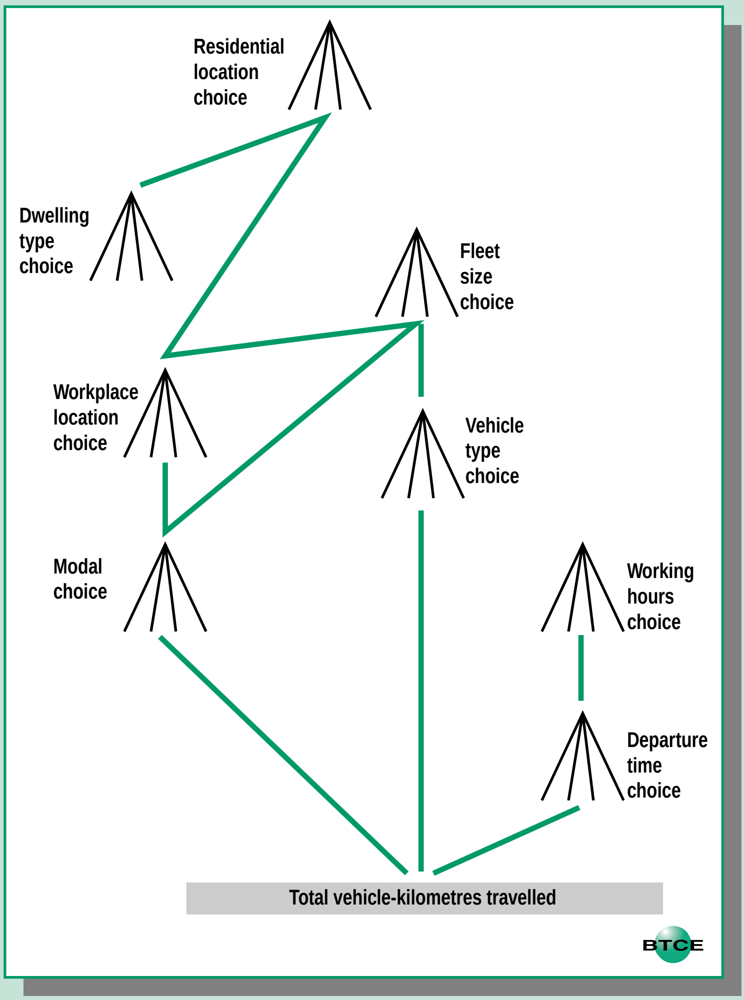
Hensher (1993, pp. 73–76, 81–82 & 87–88) provides a more formal overview of discrete choice modelling.

MEASUREMENT OF CONSUMER SURPLUS IN RANDOM UTILITY MODELS

The Inclusive Value of any cluster is the expected maximum utility of the choice set. Therefore, the expected maximum utility of the model is equal to the Inclusive Value at the root of the tree, illustrated by cluster A in figure V.2. In a logit model the Inclusive Value is the logarithm of the sum of the exponentials of expected utility (Inclusive Value) of all potential choices (also called the 'logsum'). The logsum is converted to a dollar measure of consumer surplus by multiplying by the marginal utility of income (Small & Rosen 1981, pp. 123–127), which is equal to the inverse of the parameter estimate associated with the appropriate cost variable in each model.

Total consumer surplus is equal to the population times the average consumer surplus, and, by the law of large numbers, is equal to the population times the expected consumer surplus of an individual. In a random utility model total consumer surplus is equal to the population times the Inclusive Value of the cluster at the root of the tree.

FIGURE V.3 TREE STRUCTURE OF ITS/BTCE MODEL



Source BTCE.

Changes in consumer surplus resulting from an exogenous change can be derived from the random utility model as the difference between the value of the 'logsum' before and after the policy change, multiplied by the marginal utility of income.

ITS/BTCE MODEL

The ITS/BTCE model is an interrelated model of a number of household decisions about choice of residential location, dwelling type, workplace location, number of vehicles and type of vehicles in the fleet, and commuter mode and departure time choice. The hierarchical tree structure of the ITS/BTCE model is shown figure V.3. Appendix VI describes in more detail the structure of the ITS/BTCE model and its use in policy analysis.

APPENDIX VI THE ITS/BTCE MODEL OF URBAN HOUSEHOLD TRAVEL

INTRODUCTION

The Institute of Transport Studies/Bureau of Transport and Communications Economics (ITS/BTCE) model represents urban household travel behaviour in Canberra, Sydney, Melbourne, Brisbane, Adelaide, and Perth, from 1993 to 2017. Developed by a team led by Professor David Hensher at the ITS, The University of Sydney, under contract to the BTCE, the model can be used to evaluate the effect of government policies on household travel and travel-related choices. Although designed to analyse the economic costs of reducing greenhouse gas emissions, the model also permits analysis of other urban travel issues.

In the short term, travel within cities depends on the distribution of the population, employment and facilities, on people's preferences for different transport modes, and on the method that they use to choose their routes on the urban road network. In the longer term, the nature of the transport system and the ease of access to facilities are important factors in determining where people choose to live and work, and where new facilities are developed.

Urban transport models seek to capture this complexity and to provide a means for estimating travel and traffic patterns and their evolution under different policies. Like other models of human behaviour and despite their complexity, transport models can only be rough simplifications of reality.

Cities are usually divided into zones in transport models, with travel between zones determined essentially by distance (generally measured between zone centroids), and the number of jobs, shops, schools, homes, etc., within each zone. Zones with higher concentrations of employment opportunities or retail activity, for example, would tend to attract a greater proportion of trips. Higher travel times or higher fares for public transport are reflected in such (essentially gravity) models as discouraging travel. Models with more zones (a larger origin–destination matrix) or more information about activities within each zone are correspondingly more complex.

Traditional transport models are based on a four-step procedure (described in BTCE 1996d, pp. 3–12) that utilises an origin–destination matrix to estimate the number of trips by mode between all zones in the matrix. Such models tend to be fairly weak, however, in their treatment of demand for travel—essentially the estimation of the number of trips made to and from each zone. Their strength lies in the allocation of trips between different transport modes and routes.

In contrast, the main focus of the ITS/BTCE model is on the behavioural or demand aspects of urban travel patterns. The model estimates the behaviour of households as they decide where to live and work, how to travel to work, how many vehicles to own and the type of vehicles, and other travel decisions.

Household behaviour is modelled by using the major socioeconomic characteristics of households, the available vehicle fleets, housing, and transport. Relationships reflect a variety of effects, including the effect of household income on housing choice and the effect of bus fares on commuter mode choice. To determine these relationships, a total of 1400 households were surveyed in the six Australian capital cities in 1994. The surveys covered both revealed preferences (current choices), and stated preferences (choices that people say they would make under hypothetical circumstances in the future). The use of stated preference data in estimating travel decision relationships allows the model to analyse relationships outside current or historical bounds, such as the effect of introducing electric cars.

Government policies can be simulated by changing variables such as prices for fuel, public transport fares, or the characteristics of vehicles, housing, and transport. Comparing the estimates of household behaviour before and after the changes shows the response to the policy. The results generated by the model include distances travelled, CO_2 emissions, changes in household location, travel costs, travel times, and government revenue. For instance, it can be used to determine whether a carbon tax would encourage people to increase use of public transport or to purchase more fuel-efficient vehicles.

A drawback of the model is that it is data-intensive, often requiring data that are difficult to obtain or estimate. Additionally, the current version employs only rudimentary travel networks.

HOUSEHOLD AND CITY DESCRIPTIONS

In order to determine household behaviour, descriptions are required of both the households and the city being analysed (available housing, roads, public transport, and vehicle fleet in each year of the simulation). These descriptions are a balance between simplicity and comprehensiveness. Simplicity is needed for an understandable, useable model. Comprehensiveness is required both to cover the major attributes affecting household behaviour and to allow the model to simulate a wide range of possible policies.

Synthetic households (about 600 in each city) and synthetic workers are used to represent the actual households and workers in a city. A synthetic household is described in terms of several socioeconomic characteristics, including the characteristics of any workers in the household. The behaviour of each synthetic household approximates the behaviour of the group of households in the city that have these characteristics. A weight associated with each synthetic household indicates the number of actual households corresponding to that synthetic household. For example, one synthetic household used in the model is a two-parent family with one child, a 40-year-old head of the household, a household income of $75 000, with two workers. One worker is a professional, has a $50 000 personal income and works full time. The other worker is a part time clerk, earning $25 000. The household weight of 200 indicates that there are 200 households with these characteristics in the city.

The socioeconomic characteristics used in the ITS/BTCE model to describe households and the workers within the households are shown in table VI.1. Although these descriptions do not cover all aspects of a household, they do include many of the important socioeconomic factors that influence transport-related decisions.

Each city is divided into zones with each zone described by variables such as the available housing of each type (detached, semi-detached, unit) and the number of jobs available. Table VI.1 lists the variables used to describe zones. The number of zones differs in each city depending on its size; table VI.2 shows the number of zones in each city and the regions included in the city description.

TABLE VI.1 HOUSEHOLD, WORKER AND ZONE CHARACTERISTICS

Household	*Worker*	*Zone*
Composition[a]	Profession	Distance from CBD
Household income	Personal income	Number of each dwelling type
Number of workers	Full time/part time	Number of jobs available
Age of head of household	Age	Parking cost
Number of members	Self-employed	
Weight[b]	Sex	

a. The possible types of household composition are one parent, couple without children, single person, and other.

b. The weight is the incident of the household in the city.

Source ITS under contract to BTCE.

TABLE VI.2 DESCRIPTION OF CITIES AND ZONES

City	*Coverage*	*Number of zones*
Adelaide	Adelaide	10
Brisbane	Brisbane and Ipswich Shire	11
Canberra	Canberra and Queanbeyan	6
Perth	Perth	9
Melbourne	Melbourne and Mornington Peninsula	18
Sydney	Sydney Metropolitan area and Gosford	14

Source ITS under contract to BTCE.

TABLE VI.3 TRANSPORT AND VEHICLE CHARACTERISTICS

Roads between zones	*Public transport*	*Vehicles*	*Fuel costs*
Distance Capacity Vehicle free-flow time	For each mode (bus, train light rail, busway)	Class Age Fuel efficiency	Wholesale fuel price Fuel excise
Congestion toll	Frequency	Acceleration	Carbon tax
Road toll	Fare	Vehicle mass	
	Access and egress time[a]	Sales tax	
	Journey time		

a. Time taken travelling between origin or destination and the bus stop or train station.

Source ITS under contract to BTCE.

TABLE VI.4 VEHICLE CLASSES

Conventionally fuelled vehicles	*Alternatively fuelled vehicles*
Micro	Small compressed natural gas (CNG)
Small	Medium CNG
Medium	Large CNG
Upper Medium A	Small electric
Upper Medium B	Medium electric
Large	Large electric
Luxury	
Light commercial	
Four-wheel drive	
Light trucks	

Source ITS under contract to BTCE.

TABLE VI.5 TYPES OF HOUSEHOLD AND WORKER DECISIONS

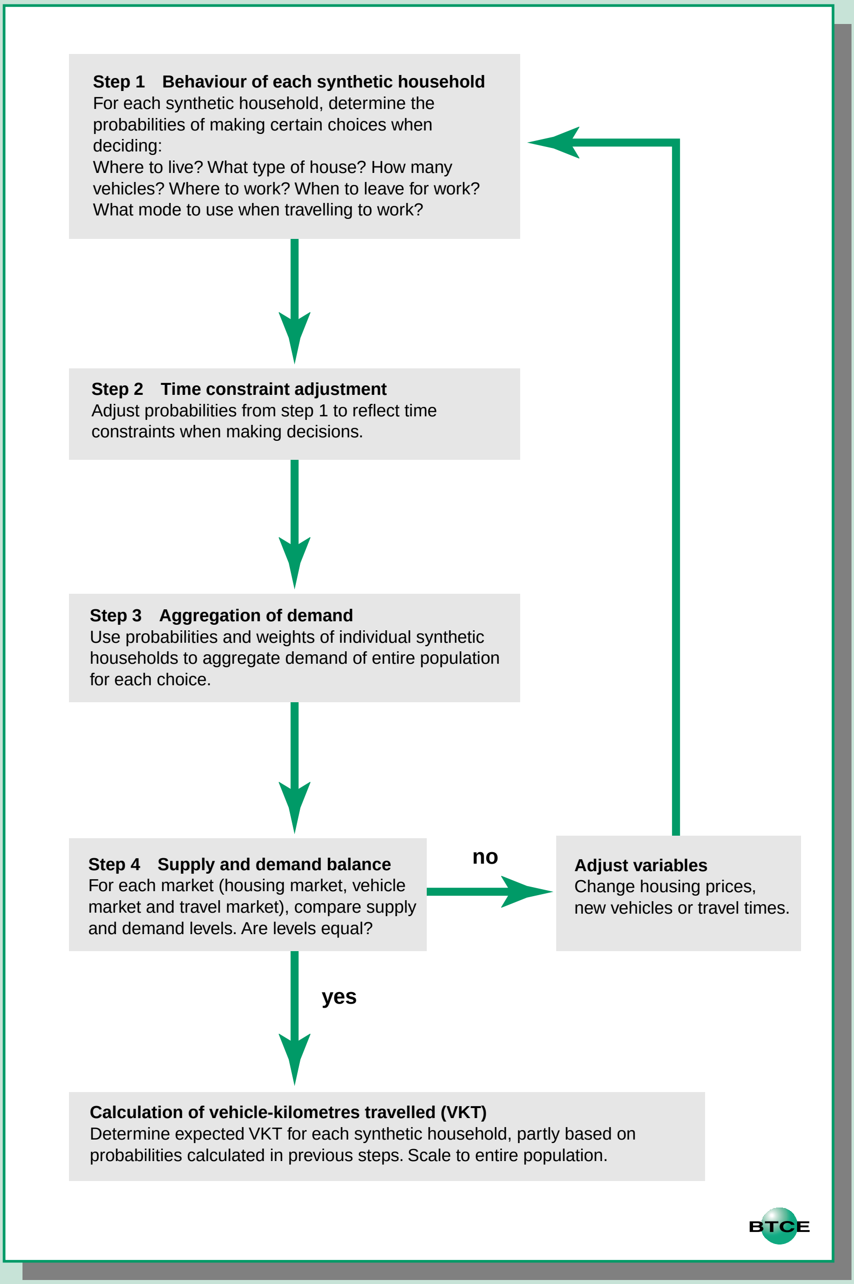
Household decisions	*Worker decisions*
Residential location	Workplace location
Type of residential dwelling	Work hours (regular, flexible)
Number of vehicles	Commuting departure time
Type of vehicles	Commuting mode
Vehicle-kilometres travelled	

Source ITS under contract to BTCE.

Roads and public transport services between any two zones are also defined in the model. All roads between any two zones are represented by one road with a specified vehicle capacity and distance. Distances are measured in kilometres between the centroids of zones. Similarly, all public transport routes between zones are consolidated into one synthetic route. Variables included in the model's transport description relate mainly to the cost and time of the journey (table VI.3).

Table VI.3 lists the characteristics used to represent the vehicle fleet. The model groups all available vehicles into sixteen classes such as small or luxury, as shown in table VI.4. Vehicle technical specifications vary according to class and vintage. Vehicle vintages include each year from 1972 to 2017 and an additional category for vehicles older than 1972.

FIGURE VI.1 ITS/BTCE MODEL OF URBAN HOUSEHOLD TRAVEL BEHAVIOUR



Source BTCE.

HOUSEHOLD DECISIONS

Once the description of households, vehicles and cities has been completed, the model estimates household behaviour. This process requires a series of five consecutive steps, as shown in figure VI.1. These steps are repeated for each year of the simulation period.

Behaviour of each synthetic household

In the first step, the ITS/BTCE model reflects the behaviour of each synthetic household through a range of decisions. Some decisions are made by (synthetic) households, while other decisions are made by individual (synthetic) workers, as shown in table VI.5.

Each decision consists of a set of choices. For instance, in the residential location decision (essentially a sub-model), households choose a zone in which to reside. The model determines the probability of making a particular choice, based on the attributes of the decision-maker and of all the possible choices. The probability may also depend on other decisions (appendix V explains the method of connecting decisions through Inclusive Value variables). In figure VI.2 an arrow between two decisions indicates that information from one decision is passed to the other.

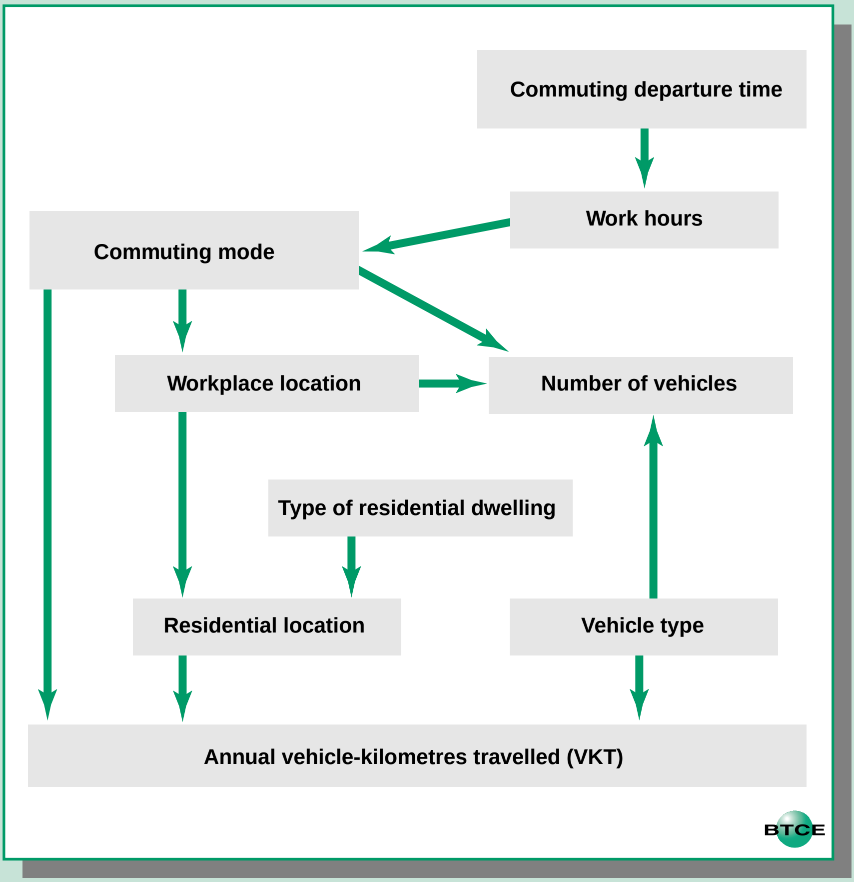
For example, one decision is the choice of transport mode for commuting. The choices available for this decision are drive alone, ride share, and available public transport options. The main attributes influencing the decision are the income of the worker and the cost and travel time of the available modes. Since cost and travel time depend on residential and workplace location decisions, commuter mode choice must be estimated for each combination of the location decisions.

Time constraint adjustment

In the second step, the probabilities of making particular choices are adjusted to simulate time constraints inherent in making decisions.

The probabilities determined in the first step represent the probabilities of making choices given unlimited time to adjust to new situations. However, various constraints prevent sections of the population from making changes immediately. For example, a worker may wish to purchase a new vehicle this year but may be restricted by finances or lack of time. The worker might then postpone the purchase for a year. To

FIGURE VI.2 LINKS BETWEEN DECISIONS IN THE ITS/BTCE MODEL



Source BTCE.

represent such constraints, the model adjusts the probability calculated in step 1 using the previous year's probability. For instance, if the probability of buying a new small car is 0.1 in the first year and 0.2 in the second year, the actual probability used by the model in the second year will be 0.16.[1]

1. The portion of the change in probability permitted between consecutive years is defined by the user of the model. In the above example, the portion would have been set to 0.6. The final probability is calculated by 0.1 + 0.6(0.2 – 0.1) = 0.16.

Aggregation of demand

Probabilities of individual synthetic households are combined in the third step to determine the demand of the entire city for each vehicle, for housing, and for travel choice. Since each synthetic household represents a group of actual households, the probability that a household makes a certain choice multiplied by the weight of the household approximates the demand of the group. The demand of the entire city can then be calculated by summing the demand of the groups of households.

For example, the second step may have determined that the probability of a synthetic household in Melbourne choosing a new luxury car is 0.1. If the weight of this synthetic household is 100, then that group of households in Melbourne would demand a total of 10 new luxury cars. The demand for luxury cars by all households can be added together to determine total demand within the city.

Balancing supply and demand in the housing, travel and vehicle markets

The demand determined in the first three steps represents the decisions that households would make independently of the decisions being made by other households. In the fourth step, the model includes the effects of households' decisions on each other, by considering the vehicle and housing markets and the network capacity constraints.

In the vehicle market, the demand for each class of vehicle is met through the supply of new vehicles. Vehicle supply is divided into two categories: old and new vehicles. The supply of old vehicles is equal to the previous year's stock minus scrapping. Vehicle scrapping occurs within the model based on the age and price of the vehicles. New vehicle supply is set equal to the difference between the number of vehicles demanded and the old vehicle supply. This process ensures that demand for each class of vehicle is met but not that demand for each vehicle vintage equals its supply.

Equilibration processes are used to represent constraints in the housing market and the vehicle travel network. For the housing market equilibration, the model first calculates the probabilities for individual household decisions (step 1) using default values for housing prices. It then calculates the difference between the demand and the supply. The demand for housing is determined in step 3. As part of the city description, the user specifies the supply of housing each year. If the supply and demand levels are not equal, the model will adjust the housing prices and repeat the household choice decisions until supply and demand are equal.

For vehicle travel time equilibration, the model initially (step 1) uses a default time for travel between two zones to calculate the total population demand for trips (volume). A second calculation based on the combination of this derived volume, the road capacity and the free-flow travel time between the zones determines a revised estimate for travel time (the derived time). If default time and the derived time differ, the model calculates a new travel time (an adjusted average of derived and default times) and repeats the household probability calculations using this new travel time. This process continues until two consecutively determined travel times are equal.

Calculation of vehicle-kilometres travelled (VKT)

Information from the previous four steps is used in the fifth step to determine total VKT. Vehicle-kilometres travelled are estimated for each synthetic household based on the attributes of the household and the city parameters. As with household decisions on residential location or transport mode, VKT values are multiplied by the weights of the synthetic households and then aggregated to determine the VKT for the total city population. The VKT calculations occur after all the other household decisions and after the equilibration process since they do not affect the other decisions or the equilibration variables.

OUTPUTS

After the model has completed these five steps, it generates an extensive description of household behaviour for the city. This description includes the number, type and price of households in each zone, the number, type and price of vehicles, and the number and transport mode of commuters travelling between any two zones.

The outputs reflect the main objectives of the current application of the model: the analysis of the costs of policies for reducing greenhouse gas emissions. For instance, the model provides estimates of CO_2 emission levels, household travel costs, and revenue. CO_2 emissions are based on total fuel consumption, determined by the fuel efficiency of vehicles and the distances travelled. Household costs of travel cover fuel costs (including the fuel excise), registration charges, tolls, congestion costs, public transport fares, and prices of vehicles. Government revenue includes sales tax, fuel excise, congestion charges, and public transport fares. Revenue from parking and road tolls are presented separately since the money could go to either private enterprise or to government agencies.

The model also generates other outputs that help describe the city and provide further levels for analysis of policy options. Table VI.6 lists outputs produced by the model.

It is possible to obtain outputs either as totals for an entire city or separately by characteristics such as income level, household composition, or residential location. Outputs are available for each year of the simulation period.

POLICY OPTIONS

Analysis of the effects of a policy measure normally begins with a basecase scenario. That is, the model is run with variables and household characteristics set to reflect current and expected future levels assuming 'business as usual' government policies. By implication, future government policies remain the same as those that currently apply. The basecase provides a benchmark for comparing the effects of changes in government policies or changes in household behaviour.

To simulate policy or behavioural options, the user can change appropriate city, transport and vehicle characteristics. The model is then run and the results reflect new household behaviour which can be compared with basecase results. For example, it is possible for the user of the model to change the carbon tax variable from the default level of zero to $10 per tonne of CO_2 equivalent. The changes in results, such as VKT, represent the effects of the policy.

Only a small number of the available policy instruments have been analysed in this Report, largely due to difficulties with the model. A list of potential instruments is given in table VI.7.

The ITS/BTCE model is not restricted to implementing one instrument at a time. Instruments may also be implemented at different times and at different intensities. For example, a government may choose to introduce a congestion charge in 1996 and construct a new light rail system in 2000 as part of the same policy.

TABLE VI.6 ITS/BTCE MODEL OUTPUTS

Output	*Description*
CO_2 emissions	CO_2 emitted from private vehicles
Household costs	Fuel, congestion toll, carbon tax, road toll, sales tax, vehicle costs, public transport fares,
Government revenue	Public transport fares, fuel taxes, congestion tolls, sales tax, carbon tax
Parking charges	Revenue from parking charges
Road tolls	Revenue from road tolls
Commuter mode choice	The number and percentage of commuters travelling by each mode
Consumer surplus	Measure of social benefits
Time	In both dollars and minutes
Vehicles	Number of vehicles
VKT	Total vehicle-kilometres travelled for the city

Source ITS under contract to BTCE.

TABLE VI.7 POTENTIAL GOVERNMENT INSTRUMENTS

Instruments
CNG or electric powered vehicles to the market
Technological improvements to vehicles
Carbon tax
Congestion pricing
Changes to existing public transport services for either bus or train
Changes to fuel excise tax
Government removal or regulation of older vehicles
Introducing busways or light rail systems
Changing parking charges
Price rebates/discounts for vehicle classes
Changing the fuel efficiency of vehicles
Changing sales tax on vehicles
Placing tolls on existing or new roads
Changing urban density
Changing vehicle registration charges

Source ITS under contract to BTCE.

PARKING CHARGE EXAMPLE

Although the following example is a simplification, it helps illustrate how all the pieces of the model fit together.

Suppose that the government wishes to analyse the effects of increasing parking charges within the central business district (CBD). The model would first be run with current charges and any forecast changes over time—the basecase scenario. For the policy scenario, the model would be run again with increased parking charges. All changes in costs and emissions relate to the differences between the basecase and the specific policy case.

An increase in parking charges would increase the cost of commuting to the CBD by car. In the model, the increased cost leads to a fall in the probability of choosing either of the car options (drive alone and ride share) for commuters working in the CBD. Consequently, the probability of workers using public transport instead of cars would increase.

A number of other changes could also occur, depending on the size of the parking charge. Vehicle fleet size (number of vehicles per household) may decrease due to the increased use of public transport. The probability of working in the CBD may also decrease as workplaces relocate to areas with lower parking charges, or workers change jobs.

All these behavioural changes will change the number of vehicles on the road. Fewer vehicles will lead to decreased travelling times for commuters using cars. When the model iterates with adjusted lower travel times, the probabilities of workers commuting by car will increase. This increase leads to a chain of decisions that are opposite to the effects of increased parking charges. The model will balance these countervailing changes through iterations with different travel times until an equilibrium is reached. Parking charges could also affect variables such as housing location if workers move closer to public transport routes.

Once equilibrated, the model determines VKT and finally the economic, social, and environmental indicators. Comparing the results from the basecase with the results from the policy scenario will indicate the effects of the policy of increasing parking charges in the CBD.

UNRESOLVED ISSUES

The ITS/BTCE model is experimental and innovative in that it uses a multinomial logit model of household travel behaviour in a reasonably complex city structure. Adjustments were made by the BTCE both to the input files and output calculations.

Changes to the model and input files

The original ITS/BTCE model assumed a uniform 1 per cent per annum rate of population growth in all of the cities modelled. ABS (1995b) data suggest that there will be wide variations in population growth both between cities and over time. For example, Adelaide is expected to grow at just below 1 per cent during the 1990s falling to only 0.5 per cent in 2015. Brisbane's population growth is currently about 2 per cent, and is expected to remain above 1 per cent up to 2015. Population growth in the input files was changed to reflect the ABS projections. Appendix table I.5 provides population projections by city.

Growth of the passenger vehicle fleet is also an important determinant of CO_2 emissions. In the original model, the ratio of vehicles to population remained constant over time in the basecase scenario, but other evidence suggests that the number of vehicles per person will grow logistically over time (BTCE 1995c, p. 27). The fleet is expected to expand until it reaches a plateau of approximately 500 vehicles per thousand people. Equations in the model were altered by the BTCE to ensure that the size of the vehicle fleet in the basecase met these expectations.

Fuel intensity in the original version of the model was equal to the intensity in 1993 for vehicles manufactured before that year or the new vehicle fuel intensity for vehicles manufactured after 1993, and held constant over the vehicle's lifetime. BTCE (1996a, p. 29) suggests that the fuel efficiency of vehicles will deteriorate as they age. To replicate this deterioration, the fuel intensity was increased to 20 per cent above the 'at new' levels over the first ten years of life. After ten years the effects of engine replacement and the retention of only the better performing vehicles lead to a slight annual fall in fuel intensity.

Changes to outputs

While the ITS/BTCE model produced a wide range of outputs, not all of them matched the BTCE's expectations. The following sections discuss some of the problems, their probable causes and the steps taken to compensate for the difficulties.

Estimating commuter VKT

The ITS/BTCE model provides two estimates of changes in car travel behaviour by commuters: the original estimate provided by the commuter VKT sub-model, and the change in the number of commuter car trips derived from the commuter mode choice sub-model. The two methods did not always produce consistent results. For example, introducing a carbon tax of $273 per tonne of CO_2 equivalent led to a 3 per cent fall in commuter trips but a 13 per cent fall in the work-related VKT from the VKT sub-model.

Because the behavioural sub-models provide a more realistic VKT estimate, the original calculation was replaced with one generated from the change in car trip results. Between them, the commuter mode and residential and workplace location choice sub-models yield the number of commuter trips between each set of zone pairs. Multiplying these results by the distance between each zone pair gives the estimate of commuter trip VKT.

It is important to note that the original VKT equation included all work-related travel (including travel during the day while at work) but the commuter trip calculation represents only the journey to and from work. Results from the commuter trip VKT estimates were therefore adjusted by the BTCE. The commuter trip VKT was multiplied by a scaling factor that represents at-work travel in each city.

Consumer surplus

One of the key outputs from the ITS/BTCE model is the change in consumer surplus caused by the introduction of greenhouse abatement measures such as road user charges. Appendix V discusses the theoretical basis for the consumer surplus being equal to the Inclusive Value of the highest level choice in the tree for a multinomial logit model. The situation is more complex for the ITS/BTCE model in that there are two separate trees and the continuous VKT calculation to be considered in consumer surplus estimation. In this case total consumer surplus is the sum of the Inclusive Values from the top level residential location choice sub-model and the fleet size choice sub-model and the surplus derived from the continuous VKT sub-model.

Regardless of the theoretical correctness of the ITS/BTCE model calculation, the actual changes in consumer surplus estimates do not match intuitive expectations. The following examples discuss outputs obtained from an urban public transport (UPT) fare reduction and a carbon tax instrument.

UPT fare reduction. In the case of UPT, it could be expected that a fare reduction would benefit commuters. Unfortunately, the ITS/BTCE model gives the opposite result. That is, consumer surplus falls after UPT fares are reduced. In a more realistic representation of the UPT fare reduction instrument commuters may have also experienced some increase in taxes to compensate for the fare reductions leading to a possible fall in consumer surplus. The ITS/BTCE model does not consider these tax implications. Fare reductions, in effect, occur (other things being equal) with no other changes.

The overall fall in consumer surplus is driven by the changes in surplus from the residential location sub-model and fleet size choice sub-model. Introducing fare reductions increases the benefits of UPT travel without adversely affecting car travel, leading to an increase in surplus from the commuter mode choice sub-model. As figure VI.2 shows, this surplus increase is passed to the residential location choice sub-model yielding an increase in surplus from this tree. The increased use of UPT services causes a small fall in the vehicle fleet and consequently a fall in consumer surplus derived from vehicle ownership.

Neither of these results is individually incorrect. But the fall in vehicle fleet size consumer surplus is larger than the gain in residential location choice surplus, causing an overall fall in consumer surplus. In terms of individual commuters and households, these results imply that the commuter will make a decision to shift to UPT (a 'no regrets' decision) and then remove a car from the household despite this removal causing a greater loss to the household as a whole than the commuter's gain from switching to UPT. It is not reasonable to assume that most commuters would behave in a way that adversely affected the household as a whole.

Carbon tax. In the case of a carbon tax, the model gives an intuitively correct fall in consumer surplus. However, the sum of the fall in consumer surplus and rise in government revenue produces a net gain to society. Given that externalities such as health and accident benefits have been excluded from the ITS/BTCE model at this stage, economic theory suggests that the sum of consumer surplus changes and government revenue changes should be negative.

There is no obvious reason for these inconsistencies, but the results from UPT fare reductions and carbon tax combined with other concerns led to the BTCE omitting the model's consumer surplus estimate from the welfare calculations of all greenhouse abatement instruments analysed in this Report. Behavioural changes derived from the choice sub-models form the basis of the new consumer surplus estimation. Details of these new welfare calculations are presented separately for each instrument in various chapters in this Report.

Professor Hensher argues that the BTCE's approach fails to take into account the complex interrelationships encapsulated within the ITS/BTCE model and that it is the complex nature of these interrelationships that leads to results that appear counter-intuitive. He points out that the BTCE's approach—which is based on preconceived outcomes driven by a non-system-wide view of isolated impacts—will inflate the BTCE's estimates of consumer surplus. The BTCE acknowledges Professor Hensher's expertise in this area and that it does not have sufficient expertise in hierarchical nested logit models to fully substantiate its own approach.

Non-CO_2 emissions

Emissions of non-CO_2 gases such as methane, carbon monoxide, nitrogen oxide and sulphur oxides are not calculated within the ITS/BTCE model. The quantity of each gas emitted has been determined by the BTCE from the VKT and the age and class characteristics of the passenger vehicle fleet. Non-CO_2 emissions were converted to CO_2 equivalents according to their global warming potential (appendix IV).

Although the model comes with a user-friendly interface which is simple to operate, problems encountered with the model itself make it preferable for users to be familiar with the input files themselves.

The ITS/BTCE model is the property of the BTCE. Enquiries should be directed to the Director, Bureau of Transport and Communications Economics, GPO Box 501, Canberra ACT 2601.

APPENDIX VII CARMOD—BTCE MODEL OF THE AUSTRALIAN CAR FLEET

Automobiles are durable goods. In OECD countries only 10 per cent of cars on the road are less than one year old (*The Economist*, 22 June 1996, p. 6), although only about 5 per cent of Australian vehicles are new each year (BTCE 1996a, appendix table II.10). Any innovation in vehicle technology which improves the fuel or emission performance of new vehicles will therefore take several years to affect a sizeable proportion of the total fleet.

To allow analysis of policies that affect portions of the vehicle population, the BTCE has developed the CARMOD model of the dynamics of the Australian car fleet. The model incorporates age-specific characteristics (based on the year of manufacture of the vehicle), and calculates vehicle utilisation for each vintage over time, allowing for vehicle ageing and scrapping.

A rudimentary model was originally developed to estimate future emissions from the Australian car fleet for BTCE (1995c). Since the publication of BTCE (1995c) in March 1995, the BTCE fleet model has been substantially revised so as to better reflect actual on-road operating conditions for Australian vehicles. The framework of CARMOD is similar to the model developed for BTCE (1995c), the main differences being the inclusion of:

- deterioration effects for fuel efficiency and emission performance as vehicles age; and
- increased emission rates for urban driving to allow for the effects of congestion.

The current version of CARMOD is internally more consistent than the previous version and permits a far larger set of inputs. It therefore allows a wider set of policy simulations. The model has been developed using a simple spreadsheet format to provide maximum transparency of the calculations and to permit users to easily change internal data and parameter values. BTCE (1996a, especially chapter 2) provides a fuller exposition of CARMOD.

It is important to note that basecase projections reported in BTCE (1995c) indicated that CO_2 equivalent emissions from the car fleet between 1995 and 2015 would change only slightly from year to year, resulting in an overall decline of about 10 per cent over the period. The revised basecase (using CARMOD) in **appendix III** of this Report again foresees car emissions changing only slightly from year to year, but with about a 10 per cent *increase* between 1995 and 2015.

MODEL STRUCTURE

Estimating fuel consumption forms the main segment of the model framework. The model decomposes annual fleet fuel consumption into four components:

$$\underset{\text{(litres)}}{\text{Fuel consumption}} = \underset{\text{(cars per '000 persons)}}{\frac{\text{Vehicles}}{\text{Population}}} \times \underset{\text{('000 persons)}}{\text{Population}} \times \underset{\text{(km per car)}}{\text{VKT}} \times \underset{\text{(litres per km)}}{\frac{\text{Average fuel intensity}}{100}}$$

Note VKT is vehicle-kilometres travelled per vehicle per annum, and the factor of 100 is included because average fuel intensity is usually quoted in terms of litres consumed per 100 kilometres travelled (litres per 100 km).

Once the model has estimated fuel consumption and total vehicle-kilometres travelled for each vintage, emissions of CO_2, methane (CH_4), nitrous oxide (N_2O), other oxides of nitrogen (NO_x), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs, both exhaust and evaporative) are calculated using vintage-specific emission rates.

To represent the total greenhouse effect from the emissions of several different gases, their emissions are expressed in terms of a common unit, CO_2 equivalent emissions, on the basis of the global warming potentials given in **appendix IV**.

The estimation methods used for each of the components of the fuel consumption equation specified above are explained separately below.

Motor vehicle ownership

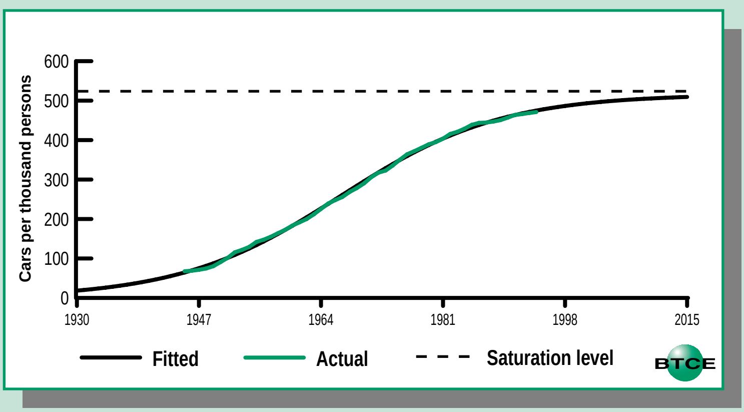
A key aspect of the CARMOD model is the projection of the number of vehicles per person.

The number of cars per thousand people for Australia was modelled as a logistic (or S-shaped) function which imposes an upper bound (or *saturation level*) on motor vehicle ownership. This approach is consistent with experience in a number of overseas economies, where exponentially increasing growth, until the 1960s or 1970s, has been replaced with slowing growth in the 1980s and 1990s.

Gruebler and Nakicenovic (1991) also found that in each of 12 developed countries studied, a logistic formulation fitted the data extremely well. Saturation levels were in the range of 550–700 cars per thousand people in North America, 300–550 in Europe, 200–250 in Japan, and 440–550 for Australia.

BTCE (1996a, p. 6) reports that the best fit of the logistic curve to Australian data was obtained with an estimated saturation level of around 520. That is, Australian car ownership is expected to level out at about 520 cars per thousand people by early next century. Figure VII.1 illustrates future levels of Australian car ownership, which is currently about 470 vehicles per thousand people.

FIGURE VII.1 PROJECTED AUSTRALIAN MOTOR VEHICLE OWNERSHIP



Source BTCE 1996a, p. 6.

Knowledge of both the population and the projected number of cars per thousand people is used to determine the total vehicle stock for a specific year. New vehicle sales are derived as the increase in total stock over the previous year plus the number of vehicles scrapped during the year.

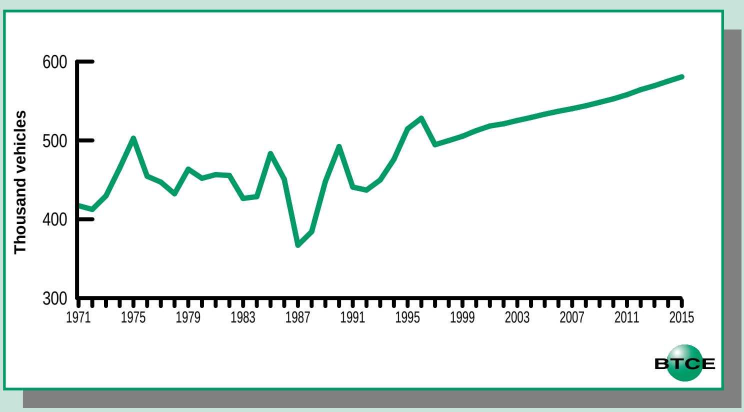
The number of cars scrapped during any year is calculated by applying age-dependent scrapping rates to vehicle stock numbers. Scrapping functions (scrapping rates by age of vehicle) are calculated from the year-to-year differences of points on vintage survival curves (curves showing the proportion of vehicles of a particular vintage surviving to a particular age).

Basecase projections illustrated in figure VII.2 show annual new vehicle sales rising from about 528 thousand cars per annum in 1996 to about 580 by 2015 . The car fleet is expected to age noticeably over the same period; with the proportion of cars aged over 20 years increasing particularly significantly by 2015 (figure VII.3).

Population

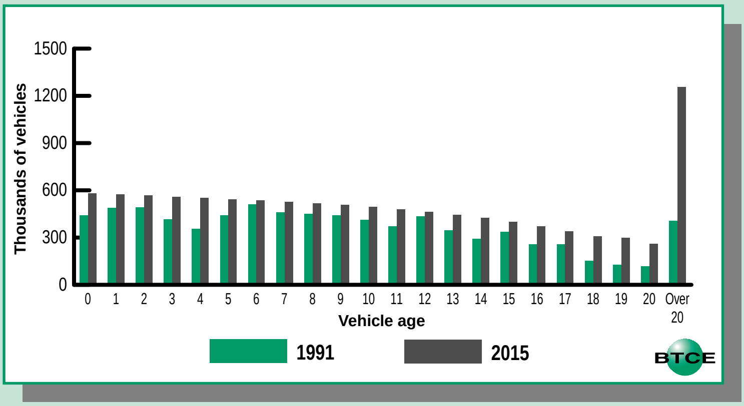
The Australian Bureau of Statistics (ABS) provides several scenarios which project the size of the Australian population. The 'A and B' scenario (ABS 1994d) was used. It assumes medium levels of fertility

FIGURE VII.2 BASECASE NEW VEHICLE SALES, 1971 TO 2015



Source BTCE 1996, p. 10.

FIGURE VII.3 COMPOSITION OF PASSENGER CAR FLEET BY AGE OF VEHICLE, 1991 AND 2015



Source BTCE 1996a, p. 10.

and low levels of immigration, resulting in a projected Australian population in 2014–15 of 21.6 million people (up by 22.3 per cent on the 1993 level). Alternative population scenarios can easily be entered by the user into the CARMOD model.

Multiplying projected population growth and projected vehicles per person yields a projection of total vehicle numbers. The basecase estimate of the Australian fleet is 11 million cars by 2015.

Vehicle utilisation

Average vehicle-kilometres travelled (VKT) was assumed to remain constant at 15 500 kilometres per car per year; in keeping with the trend over the last couple of decades (BTCE 1996a, appendix table II.2).

Several factors may influence the average distance that a car is driven. Increasing incomes would tend to increase the demand for mobility, and therefore the utilisation of cars. On the other hand, traffic congestion in Australian cities is likely to increase over the next 20 years, as is the incidence of two and three car households, thus lowering the average utilisation per vehicle. The increasing average age of the Australian adult population could also reduce average VKT in the future.

Since these effects appear to roughly counterbalance each other, fleet VKT per vehicle was kept constant at 15 500 km per year in the basecase. CARMOD permits changes to average fleet VKT to suit different policy simulations.

For each year of the projections, the model adjusts the average VKT for each vintage so that VKT averaged over the whole fleet population agrees with the input value for that year. Total distance travelled by the fleet is apportioned between the vintages based on the distribution of VKT by age of vehicle given by the 1991 *Survey of Motor Vehicle Usage* (ABS 1993a). The distribution set for the basecase, which has a new vehicle travelling on average over twice as far in a year as a 20-year-old vehicle, is given in BTCE (1996a, table 2.2). To allow for cars being purchased throughout the course of a particular year, it is assumed in CARMOD that average new car VKT *in that year* is half of average annual VKT (that is, 12 250 km).

Basecase projections are that total passenger car travel will increase by 28 per cent between 1995 and 2015, to be 170.5 billion kilometres by 2015 (BTCE 1996a, appendix table II.1).

Average fuel intensity of the car fleet

The average fuel intensity (litres per 100 km) of the cars in the Australian fleet is a crucial variable in forecasting fuel consumption. To forecast the average fuel intensity for the fleet as a whole adequately, it is necessary to adopt an approach like that in CARMOD: that is, monitoring vehicles of different vintages from their entry into the fleet, through to the time that they are scrapped.

Technological improvement

Connected with each vintage are fuel intensity characteristics. It was assumed that the *rated* (as opposed to on-road) fuel intensity of new cars entering the fleet falls from its current level of slightly below 9 litres per 100 km to 8.06 litres per 100 km in 2004–05. Based on car industry product plans adjusted to account for the introduction of anticipated new standards for vehicle emissions and safety by the end of the century, this decline in fuel intensity constitutes the basecase projection of a study done for the Federal Office of Road Safety (FORS) on the potential to improve car fuel economy (Nelson English, Loxton & Andrews 1991a, p. 49). Fuel intensity is assumed to fall further to 6.5 litres per 100 km (a maximum technology scenario for 2004–05) by 2014–15 on the basis of Nelson English, Loxton & Andrews (1991a, p. 46). That is, the BTCE has assumed that what is considered the maximum fuel efficiency attainable in 2005 (using currently known technologies) becomes the readily achievable level 10 years later.

Implicit in these projected declines in fuel intensity is the assumption that the composition of new car sales by vehicle size remains similar to the current sales mix. That is, the proportions of total sales due to small, medium and large cars stay the same, and the shift to higher average engine sizes apparent in the 1980s ceases.

Rated fuel intensities of new cars are based on trends in national average fuel consumption (NAFC), which is in turn based on dynamometer cycle tests. However, on-road driving conditions can differ markedly from test drive cycles. Factors such as the effects of traffic congestion, differing road types and aggressive driving mean that 'real world' fuel consumption is about 20 per cent higher than results given by the dynamometer tests used to estimate NAFC. The BTCE CARMOD includes conversion factors for scaling up cycle test values to better reflect on-road driving conditions.

The current difference between NAFC and on-road fuel consumption is set to 18 per cent in CARMOD. Since improvements in engine management systems are allowing the on-road fuel consumption of new vehicles to be closer to cycle test results (Watson 1992), the basecase assumes that the difference declines to 12 per cent by 2015. The basecase thus assumes that current on-road average fuel intensity of 10.4 litres per 100 km will decline to 7.3 litres per 100 km by 2015. Alternative scaling factors for the gap between tested and on-road fuel consumption can be entered by CARMOD users.

Deterioration

Changes in average fuel consumption for a vintage appear to consist of two trends: deterioration with age of each vehicle in the vintage, and the eventual scrapping of the less efficient members of the vintage. For each vehicle of a vintage, deterioration was assumed to cause fuel intensity to increase by about 3 per cent per annum, up to a limit of 20 per cent greater than when new, remaining constant thereafter. After about 10 years, the average fuel intensity of the vintage is assumed to start declining slowly, as the worst performing members of the vintage drop out of use. CARMOD incorporates a vintage ageing factor which is the result of combining these two opposing trends.

The default (basecase) ageing factor increases the average fuel intensity of a vintage from the value when new to be 20 per cent higher after 10 years, and then decreases the fuel intensity to be 10 per cent higher than when new after 20 years. Such a pattern is exhibited when values of fuel intensity by year of manufacture in 1991 are plotted against the estimated litres per 100 km when new for each vintage. The vintage ageing factor can be varied by the model user to suit the assumed scenario.

Congestion

The level of traffic congestion in major Australian cities is likely to increase considerably over the next 20 years. CARMOD basecase projections have total passenger vehicle travel increasing by about 30 per cent by 2015.

To allow the inclusion of congestion effects, total vehicle-kilometres travelled are divided in the model between urban and non-urban travel. The basecase has the proportion of total kilometres due to urban travel remaining constant (through to 2015) at the current level of 70 per cent. The proportional split between urban and non-urban travel has not changed appreciably over the last 10 years (ABS 1993a and earlier; Apelbaum 1993).

Based on analysis in the literature of the dependence of urban fuel consumption rates on average travel speed and traffic congestion levels, increases of 30 per cent in kilometres travelled could increase the fuel intensity of urban vehicles by 5 to 10 per cent (Poldy & Evill 1995; Watson 1995; Waters 1992). Taking into account the trends in utilisation of other vehicle types implies even higher congestion levels are possible. The BTCE basecase projections for road freight (appendix III) show strong expected growth in freight vehicle use, particularly for light commercial vehicles. The BTCE basecase projections imply that total urban travel (all vehicle types) could rise by as much as 50 per cent by 2015. Since urban road provision and improvements to traffic management will probably continue throughout the period, it was assumed that traffic levels under congested conditions increase by 30 per cent (rather than the full 50 per cent). It was assumed in the basecase that the 30 per cent increase in congestion causes a 10 per cent increase in the average fuel intensity of urban vehicles.

Combining the results of the effects of technological improvement, deterioration and congestion gives a basecase projection of fleet average fuel intensity declining from 12.1 litres per 100 km in 1995 to 10.9 litres per 100 km by 2015, as industry efficiency programs reduce (on-road) new car fuel intensities from 10.4 to 7.3 litres per 100 km.

Total fuel consumption

The vintage-specific figures for fuel intensity and average VKT permit estimates to be made of total fuel consumption by the Australian passenger car fleet for any particular year.

Total basecase fuel consumption by cars is projected to increase by 15 per cent, from 549 PJ in 1995 to 634 PJ in 2015.

Emissions

Greenhouse gas emissions arising directly from road vehicles consist of exhaust emissions and fugitive emissions.

About 97 per cent of NMVOC emissions from petrol vehicles consists of hydrocarbons. Estimates of fluorocarbon emissions from the transport sector are provided in BTCE (1995c, p. 5), together with average leakage rates from vehicle air-conditioners (BTCE 1995c, pp. 193–194). CARMOD estimates emissions of all the other species mentioned above, on a year-by-year basis.

The accurate estimation of mobile source emissions is complex because emission levels depend on a large number of factors, including:

- class of vehicle and type of pollution control equipment fitted;
- type of fuel consumed and the average rate of fuel consumption;
- condition of vehicle (such as vehicle age and level of maintenance); and
- operating characteristics (such as driver behaviour, weather conditions, road type and traffic levels).

Calculation of greenhouse gas emissions from the combustion and evaporation of fuels in mobile engines is carried out by converting activity data (either fuel consumption or distance travelled) to an emission estimate through multiplication by a conversion factor or emission rate (appendix IV).

Estimates of CO_2 emissions are based in CARMOD on the assumption of full carbon combustion (see appendix IV).

Emissions are calculated in CARMOD on a very disaggregated basis, and allow inputs for changes due to cold versus hot start ratios, greater scrapping of old vehicles (including the removal of gross polluting vehicles), introduction of new technology, deterioration of emission control technology with vehicle age, and future reduction of both exhaust and evaporative emission rates (for example, due to vehicle inspection campaigns).

Technological improvement

Passenger car emission rates depend principally upon the type of emission control technology fitted to the vehicle. CARMOD includes separate emission rates for the following categories of vehicles, according to year of manufacture:

- post-1985;
- 1981–1985;
- 1976–1980;
- pre-1976.

The pre-1976 group of cars essentially has no emission control, the 1976–80 and 1981–85 groups use a variety of non-catalytic controls such as exhaust gas recirculation, and the post-1985 group uses catalytic control. About 80 per cent of post-1985 petrol cars are fitted with three-way catalytic converters, and most of the remainder are fitted with oxidation (or two-way) catalysts.

Emission standards for new cars were last set by the Federal Government in 1986, with the introduction of unleaded petrol and catalytic converters. Emission standards are expected to be made more stringent in 1997 (table VII.1). The basecase assumes that new cars manufactured after 1997 have emission rates equal to the proposed standards. The gradual replacement of older vehicles in the fleet with newer, lower-emission vehicles is therefore reflected in CARMOD. Emissions of non-CO_2 gases from cars are expected to decline steadily over time as vehicles purchased after 1986 and 1997 come to predominate in the fleet.

New vehicle emission rates are generally derived from dynamometer tests using specified drive cycles. Australian Design Rules (ADRs) for motor vehicles specify compliance with emission standards under two drive cycles: ADR 37 for vehicles manufactured after 1985, and ADR 27A for vehicles manufactured prior to 1985. Since many on-road driving conditions are not adequately simulated by test drive cycles, the emission rates derived tend to underestimate urban emission levels. As for the fuel intensity methodology, the BTCE CARMOD includes conversion factors for scaling up cycle test values to better reflect on-road driving conditions.

Conversion factors for urban and non-urban driving are given in table VII.2, where it is assumed that non-urban emissions are similar to those of the drive cycle portion that simulates freeway conditions. For example, CO emissions from a post-1985 car are estimated to be 50 per cent higher than the ADR 27A cycle during urban driving and 40 per cent lower during non-urban driving.

TABLE VII.1 EMISSION STANDARDS FOR NEW PASSENGER CARS

(g/km)

Year of introduction	*CO*	*HC*	*NO_x*
Current standard 1986	9.3	0.93	1.93
Proposed 1997	2.1	0.26	0.63

Source FORS 1993.

TABLE VII.2 CONVERSION FACTORS FOR DRIVE CYCLE TO ON-ROAD EMISSION RATES

Sector	*Vehicle type*	*HC*	*CO*	*NO_x*
Urban	Pre-1986	1.20	1.26	1.10
	Post-1985	1.38	1.50	1.36
Non-urban	Pre-1986	0.9	0.8	0.85
	Post-1985	0.6	0.6	0.85

Note Drive cycle refers to tests under ADR 27A.

Sources BTCE estimates; Watson 1993; FORS 1995; Carnovale et al. 1991; BTCE 1995c; EPA 1995.

Studies show that most new vehicles have better emission performance than the current emission standards (Carnovale et al. 1991; SPCC 1989). The basecase assumption of new cars between 1997 and 2015 simply meeting the proposed emission standards could therefore be viewed as conservative. However, the proposed standards are probably reasonable as a basecase level for future emissions over an ADR 27A drive cycle because they are:

- significantly lower than the current level, and
- given in terms of the ADR 37 drive cycle which typically returns over 20 per cent lower emission rates than ADR 27A drive cycle tests (FORS 1995; Carnovale et al. 1991; SPCC 1989).

Deterioration

As for fuel consumption, emission rates generally increase as a vehicle ages, even with newer emission control technology, particularly since catalytic converter efficiency decreases over time. Deterioration in emission performance can occur due to gradual wearing of vehicle components, poor levels of maintenance, oxygen sensor failure, tampering with emission control equipment and engine modifications.

Emission rates (in g/km) in CARMOD incorporate deterioration factors (in g/km extra per annum). The default values, which are to be added each year to the previous year's emissions rates, are given in table VII.3.

TABLE VII.3 DETERIORATION RATES FOR PASSENGER CAR EMISSIONS

(g/km/annum)

Emission	*Pre-1986 vehicles*	*Post-1985 vehicles*
CO	1.2	1.0
HC	0.07	0.06
NO_x	0.05	0.05

Sources BTCE estimates; Watson 1993; FORS 1995; Carnovale et al. 1991; EPA 1995; Waters 1992.

Congestion

To allow for future changes in average driving patterns, separate emission rates (BTCE 1996a, appendix II) are included in CARMOD for:

- cold starts (typically, the first two to three minutes of a trip, before engine and emission catalyst reach optimum operating temperature);
- stable or free-flow driving conditions; and
- driving under congested conditions or on minor roads.

The ADR 27A drive cycle emission rates are disaggregated into portions representative of the above driving conditions (using the results of Bendtsen & Thorsen 1994, Carnovale et al. 1991, Hoekman 1992, FORS 1995 and EPA 1995).

The default values are that, for an average trip, 10 per cent of the travel time is due to cold start driving, 60 per cent under stable conditions and 30 per cent on congested or minor roads (based on Adena & Montesin 1988, Bendtsen & Thorsen 1994, Carnovale et al. 1991). These proportions will tend to vary over time, as the level of urban congestion rises (as discussed above). The basecase has the average trip composition for urban travel by 2015 changing to 10 per cent of the travel time for cold starts, 50 per cent for stable driving and 40 per cent on congested or minor roads.

BASECASE EMISSION PROJECTIONS

Running CARMOD using default assumptions results in a basecase projection of CO_2 emissions from the car fleet in 2015 of about 15 per cent above the 1995 level. As a result of the increasing penetration of catalytic converter technology throughout the fleet, the BTCE expects that CO, CH_4 and NMVOC emissions from cars will decline by around 25 per cent, NO_x will decline by around 5 per cent, but N_2O emissions will approximately double by 2015 (see BTCE 1996a, appendix II, for detailed numerical tables).

Total CO_2 equivalent emissions from cars are projected to increase to nearly 50 million tonnes (9.3 per cent higher than 1995 levels) by 2015.

APPENDIX VIII TRUCKMOD—BTCE MODEL OF THE AUSTRALIAN COMMERCIAL ROAD VEHICLE FLEET

Developed by the BTCE during 1995, TRUCKMOD is a model of the Australian truck fleet and road freight task. It provides estimates of the size of the aggregate freight task, the number of new vehicles, the size of the vehicle stock required to undertake the task, total fuel usage, and total emissions produced by vehicle usage. A fuller description is provided in BTCE (1996e).

TRUCKMOD apportions the total freight task, vehicle usage, fuel consumption and greenhouse gas emissions by age of vehicle. It allows the simulation of both the timing and the effectiveness of policies designed to reduce greenhouse emissions from road freight transport. In its present form, the model contains annual data, observed and projected, for the period 1971 to 2015.

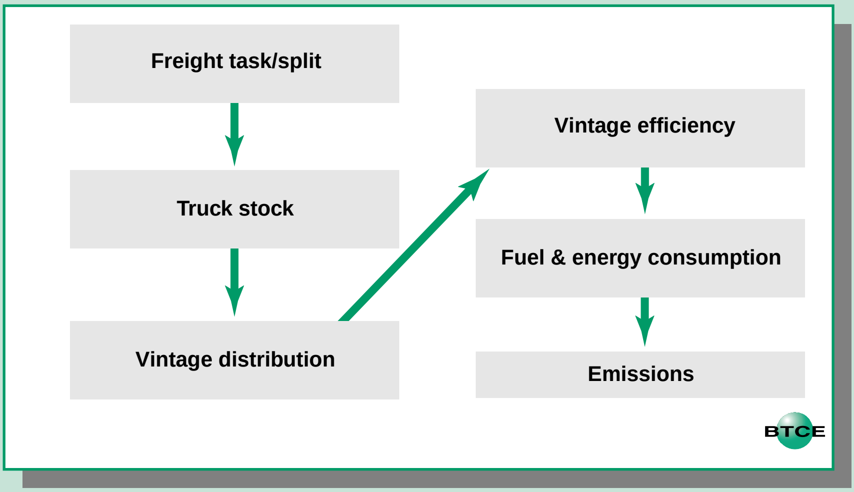
The main output from the model includes:

- the annual number of new vehicles entering the fleet each year;
- the number of vehicles scrapped annually, by vehicle age;
- fuel consumption, by vehicle age; and
- total emissions by type of gas, and total CO_2 equivalent emissions.

To run the model, the required exogenous inputs include:

- the estimated initial total stock of vehicles in the fleet;
- average annual kilometres travelled by each vehicle; and
- average fuel intensity (litres/100 km), by vehicle vintage (that is, cohort or year of vehicle manufacture).

FIGURE VIII.1 BROAD STRUCTURE OF TRUCKMOD



Source BTCE.

TRUCKMOD is composed of six main elements or sub-models (figure VIII.1):

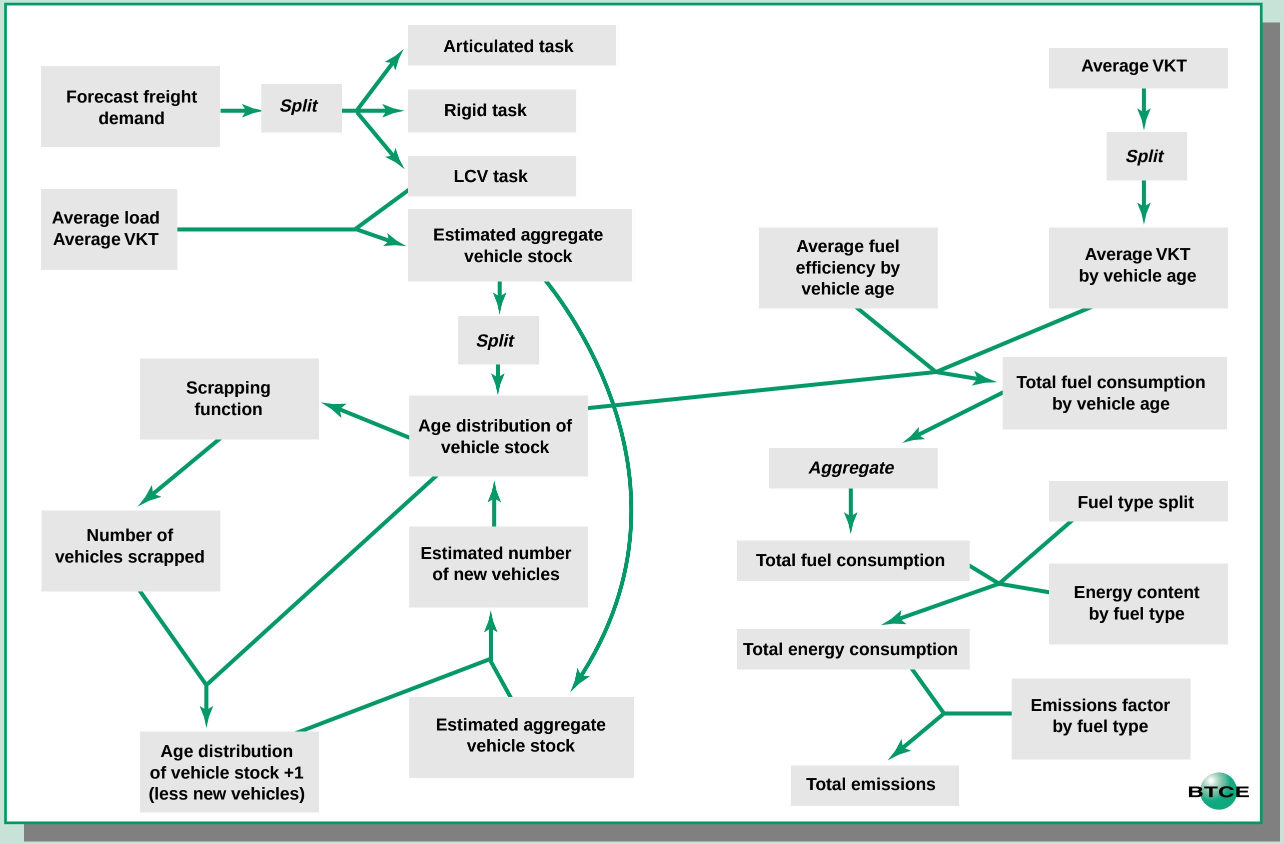
- Task/split sub-model;
- Vehicle stock sub-model;
- Vintage distribution sub-model;
- Vintage efficiency sub-model;
- Fuel and energy consumption sub-model; and
- Total emissions sub-model.

These functions are highlighted in a more detailed flow chart of the model, presented in figure VIII.2.

TASK/SPLIT SUB-MODEL

The task/split sub-model performs two operations. The first operation determines the total road freight task. The second apportions the aggregate road freight task across the three different vehicle types: articulated trucks, rigid trucks and light commercial vehicles (LCVs).

FIGURE VIII.2 DETAILED STRUCTURE OF TRUCKMOD



Source BTCE.

TRUCKMOD uses the forecast aggregate freight task as the main determinant of the number of vehicles in the fleet. Forecasts of the aggregate freight task are based on an empirical relationship between aggregate freight tonne-kilometres, real GDP and real (long-haul) average road freight rates.

The estimated relationship has the following functional form:

$$\underset{}{\text{lnTOTFRT}} = \underset{(-3.6)}{-4.46} + \underset{(14.9)}{1.058}\ \text{lnRGDP} - \underset{(-12.8)}{0.923}\ \text{lnRROADLH} \qquad (1)$$

$\bar{R}^2 = 0.99$

Estimation: Cochrane–Orcutt iterative technique

Estimation period: 1964–65 to 1990–91.

where

lnTOTFRT	natural log of total road freight task (measured in tonne-kilometres);
lnRGDP	natural log of the expenditure measure of gross domestic product (GDP(E)) at constant 1989–90 prices; and
lnRROADLH	natural log of the real road freight rate for long-haul road freight.

The t-ratios of the significance of the parameter estimates are given in parentheses. See BTCE (1995c, p. 38) for further details about the regression results.

Assumptions for basecase projections of freight task and split

Basecase projections of the total road freight task are determined by assumptions about future GDP growth and future trends in real road freight rates.

In the basecase it is assumed that real GDP will grow by 3.2 per cent per annum to 1997–98 and by 3.3 per cent per annum from 1997–98 to 2014–15. These assumptions are based on BIS Shrapnel long-term forecasts for the Australian economy (BIS Shrapnel 1993).

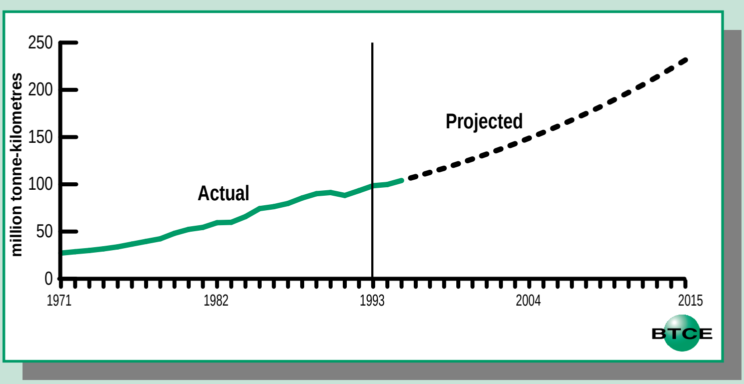
Real road freight rates are assumed to fall by 15 per cent over the period from 1992–93 to 2014–15. It is arguable that heavier loads will be carried per truck as B-doubles and other trailer combinations become more common in the Australian truck fleet, with resulting decreases in freight rates. This accords with recent experience. Between 1970 and 1990, real long-haul road freight rates declined by approximately 46 per cent. Over a similar period, the average freight carrying capacity of articulated trucks has increased from 16.4 tonnes in 1971 to 23.4 tonnes in 1988, an increase of approximately 43 per cent. The projected decline in real road freight rates over the next 20 years is well within past experience.

Based on these assumptions, the total road freight task (in tonne-kilometres) is projected to grow at approximately 4 per cent per annum from 1992–93 to 2014–15. Figure VIII.3 illustrates the total road freight task growing along an exponential growth path to 2015.

The projected aggregate road freight task is allocated in TRUCKMOD between the different vehicle types according to the following assumptions:

- tonne-kilometre task undertaken by LCVs is assumed to grow by 5.8 per cent per annum (similar to growth experienced during the 1980s);
- tonne-kilometre task undertaken by rigid trucks is assumed to grow by 3 per cent per annum (similar to growth in 1970s and 1980s); and
- the remaining growth projected for the total tonne-kilometres task is allocated to articulated trucks, and is therefore assumed to grow at about 3.8 per cent per annum.

FIGURE VIII.3 TOTAL AUSTRALIAN ROAD FREIGHT TASK, 1971 TO 2015



Source BTCE estimates.

These assumptions imply that the total task of each of the three vehicle types will grow over the period to 2015, but the rigid truck share of the total task will shrink each year to 2015. The share of the road freight task for each vehicle type is shown in figure VIII.4. Historical patterns are presented in BTCE (1996e, appendix table III.1).

The implicit assumption underlying these assumed growth rate differentials is an expectation that there is greater scope for growth in small suburban delivery type services such as pizzas or lawn-mowing, undertaken by smaller commercial vehicles, than there is for large commercial vehicles. It is also likely that groceries and possibly small consumer durables will be increasingly home delivered, fuelled by the convenience and increased availability of teleshopping and other new communications services.

VEHICLE STOCK SUB-MODEL

The vehicle stock sub-model provides an estimate of the total vehicle stock required to undertake the total road freight task. Assumptions about the average load size and the average distance travelled by vehicle type for each year to 2015, are combined with the estimated aggregate freight task (from the task/split sub-model) to derive an estimate of the total vehicle stock required to handle the estimated total freight task.

Assumptions for basecase projections of truck stocks

In the basecase the average load of articulated trucks is assumed to grow by about 0.7 per cent per annum, similar to growth rates during the 1980s.

For rigid trucks, the average load is assumed to increase by 1 per cent per annum.

Average loads for urban LCVs are assumed to increase at 1.6 per cent per annum, and those for non-urban LCVs by 2.3 per cent per annum (roughly equal to growth rates in the 1980s and early 1990s).

These assumptions are based on the expectation that competition will continue to force road freight operators to increase the intensity of vehicle use. Increased average loads reflect this expected increase in vehicle utilisation. The assumed magnitude of growth in average loads is in line with past trends. Over the past twenty years the average load of articulated trucks has increased at approximately 1.04 per cent per annum, for rigid trucks at 0.90 per cent per annum, and for LCVs at 2.45 per cent per annum. These assumptions are also used in BTCE (1995c, pp. 38–39).

The overall effect of these assumptions is:

- average vehicle-kilometres travelled (VKT) is assumed to remain constant from 1991 to 2015 for each vehicle type;
- average load is forecast to grow by approximately 48 per cent for LCVs, 24 per cent for rigid trucks, and 17 per cent for articulated trucks over the period 1991 to 2015.

Actual and projected average loads and average VKT are presented in BTCE (1996e, appendix tables III.2 and III.3).

VINTAGE DISTRIBUTION SUB-MODEL

The vintage distribution sub-model provides estimates of the age profile of the vehicle fleet for each year from 1991 to 2015.

The estimated vehicle stock is allocated by vehicle age using the actual 1991 age distribution of the vehicle fleet, obtained from the Motor Vehicle Census 1991 (ABS 1992b). The age distribution of the fleet for each year from 1992 to 2015 is then derived by applying the estimated scrapping function (described below) to the 1991 distribution, for each vehicle type.

The scrapping function

In order to build the vintage-specific part of TRUCKMOD, it was necessary to obtain information about the rates of scrapping of commercial vehicles. Using information from the ABS (1993d and earlier issues), age-specific scrapping rates were estimated for each vehicle type (BTCE, 1996e, appendix II).

To derive the age distribution of the fleet for each year from 1991 to 2015, the scrapping function is applied in the following manner. The total number of vehicles scrapped each year is derived by applying the age-specific scrapping function to the age distribution of the vehicle fleet. The number of new vehicles entering the fleet each year is then calculated as the difference between the forecast aggregate stock of vehicles in the fleet in each year (from the vehicle stock sub-model) and the size of the vehicle stock in the previous year, less the number of vehicles scrapped the previous year.

The process is repeated for each year from 1991 to 2015, giving an age distribution of the vehicle fleet for each year from 1991 to 2015, for each vehicle type.

The key assumptions underlying the scrapping function are:

- the scrapping function is assumed to be a logistic function. (Note that this means the number of vehicles remaining in the fleet, by vintage, follows a logistic function. The conditional scrapping rate—the rate at which vehicles remaining in the fleet are scrapped—is also an S-shaped function.); and
- scrapping rate functions are assumed to remain constant across different vintages. This may not be a realistic assumption, but is adopted because of the difficulty in determining whether scrapping rates vary between different vehicle vintages. There was insufficient data to provide estimates of any change in scrapping rates across different vintages.

VINTAGE EFFICIENCY SUB-MODEL

The vintage efficiency sub-model calculates total fuel consumption by vehicle vintage and vehicle type for each year from 1991 to 2015.

Calculating total fuel consumption is again a two-step process. The first step takes fleet average VKT and allocates this across all vehicle vintages to derive a profile of average VKT by vehicle age. The second step then uses the average VKT age profile, the average fuel efficiency age profile and the vehicle stock age profile to calculate total fuel consumption of each vehicle vintage.

For years beyond 1993, average fuel efficiency for each vintage is based on assumptions about average fuel efficiency of new vehicles and the rate of deterioration in vehicle fuel efficiency.

As a vehicle ages, it is assumed that its fuel efficiency will deteriorate. Deterioration will tend to reduce the average fuel efficiency of the vintage. At the same time, as the vehicle fleet ages, vehicles will drop out of the fleet through natural attrition. It is assumed that the less fuel-efficient vehicles will drop out of the fleet first, improving the average fuel efficiency of that vehicle vintage. Deterioration in fuel efficiency and natural attrition will therefore have offsetting effects on average fuel efficiency for a particular vintage.

It is assumed that for each vintage of commercial vehicle, the deterioration effect outweighs the attrition effect over the first 10 years, so that average fuel consumption deteriorates at approximately 1 per cent per annum up to 10 years. After 10 years of age, the natural attrition effect outweighs the deterioration effect, so that the average fuel efficiency of a 20-year-old vehicle is about 10 per cent worse than that of a new vehicle. (The projected basecase fuel efficiency for all commercial vehicles and the assumed deterioration in vintage average fuel efficiency are given in BTCE (1996e, appendix tables III.4 and III.5.)

Under the basecase the fuel intensity of new vehicles (litres / 100 km) is assumed to decrease over the forecast period by 10 per cent for petrol vehicles and 15 per cent for diesel vehicles. These assumptions result in a 20 per cent reduction in fleet average fuel intensity for articulated trucks between 1993 and 2015 (reflecting the lagged effect of efficiency gains in the early 1990s).

The average fuel intensity of LCVs is assumed to remain unchanged. The implicit assumption is that advances in new engine fuel efficiency will be offset by increases in vehicle size, so that new LCVs will maintain the same average fuel intensity as at present.

Average VKT enters the model as the average VKT travelled each year by all vehicles. To derive total fuel consumption, the fleet average VKT is split into average VKT by vehicle age. This is achieved by applying the 1991 VKT age distribution to each subsequent year in the model (BTCE 1996e, appendix table III.6).

Total fuel consumption for each vehicle age group is calculated for each year by multiplying the number of vehicles, the average fuel efficiency, and the average VKT for each vehicle age group. Total fuel consumption for each year is then obtained by aggregating over age groups.

Assumptions for basecase projections of vintage efficiencies

The main assumptions made in the basecase are:

- new vehicle average fuel efficiency improves by 30 per cent between 1995 and 2015 (a 1.32 per cent increase per year);
- vintage-specific average vehicle fuel efficiency deteriorates according to the deterioration schedule (BTCE 1996e, appendix table III.5); and
- the distribution of VKT by vehicle age is based on two parts: the average VKT travelled by the fleet, which was assumed to be constant in the basecase, and the distribution of average VKT by vehicle age.

The age distribution of average VKT is derived by applying an intensity of use function distribution to the fleet average VKT. It is assumed that newer vehicles are used more intensively (travel more VKTs) than older vehicles. For LCVs, for example, the intensity of use function is piecewise linear and assumes that brand new vehicles are driven, on average, 1.4 times further than the fleet average, down to 21 to 30-year-old vehicles which are used, on average, only 0.35 times as intensively as the fleet average.

FUEL AND ENERGY CONSUMPTION SUB-MODEL

Total energy consumption is derived from total fuel consumption by using the energy content per unit of fuel for each different fuel type.

To estimate total energy consumption the model splits total fuel consumption by fuel type (automotive gasoline, diesel, liquefied petroleum gas (LPG) and liquefied natural gas (LNG) based on assumptions about the proportion of total fuel consumption attributable to each fuel type. The present fuel type split is assumed to remain approximately constant until 2015. Total energy consumption is then estimated by applying the unit energy content of each fuel type to total fuel consumption of each fuel type, for each year 1991 to 2015. Detail on the fuel type split and the energy content of different fuel types is given in BTCE (1996e, appendix tables III.7 and III.10).

Using this approach the fuel type split is assigned in an ad hoc manner. It would be desirable to split fuel use by fuel type before calculating total fuel consumption, within the vintage efficiency sub-model. However, the increased complexity of the model, and, more importantly, the fact that the required data are not available, are the main reasons for assigning fuel usage by fuel type after deriving total fuel consumption.

TOTAL EMISSIONS SUB-MODEL

The carbon content per litre of each fuel type is fixed. The yield of CO_2 emissions upon combustion of a given volume of fuel is therefore given by a fixed emissions factor for each fuel type. Multiplying total fuel consumption by the relevant emission factor gives the total quantity of CO_2 emissions for each fuel type.

Following IPCC conventions (OECD 1991b), CO_2 emissions are calculated on the assumption that all of the carbon contained in the fuel is oxidised. In practice, a portion of the carbon in the fuel will not be completely oxidised and will be released as CH_4, CO and NMVOCs emissions. In TRUCKMOD actual CO_2 emissions in each year are estimated by subtracting the carbon content of CH_4, CO and NMVOCs from the calculated CO_2 emissions. This avoids any double counting of carbon released into the atmosphere. BTCE (1995c, pp. 171–173) gives a more detailed description of the method used for calculating emissions.

The model also includes average emission factors for nitrogen oxides (NO_x), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), and non-methane volatile organic compounds (NMVOCs) emissions (BTCE 1996e, p. 74). Emission rates will vary with the efficiency of the engine and conditions during combustion. Over the past decade, advances in engine technology have led to large reductions in emissions and increased fuel efficiency. Driven largely by increasingly stringent regulations, rates of vehicle emissions are expected to be further reduced. It is assumed in the model that emissions of non-CO_2 gaseous emissions fall at the same rate as emission of CO_2. The model permits assumptions about differing emission rates for different gases.

The model also includes the global warming potential (GWP) of the different gases to provide a numeraire in terms of their contribution to global warming. The GWP is used to convert emission levels of each gas into CO_2 equivalent emissions. Summing over all gases gives total CO_2 equivalent emissions from the road freight task. The GWPs used in the model are given in **appendix IV**.

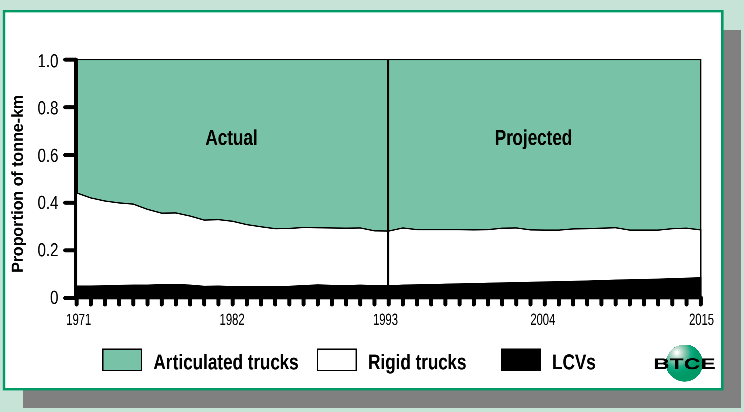
LIMITATIONS OF TRUCKMOD

TRUCKMOD is the BTCE's first approximation to a dynamic model of the Australian truck fleet and road freight task. For the purposes of analysing possible policy options, the major limitations of TRUCKMOD in its present form are:

- There are no endogenous feedback effects built into the model apart from the scrapping function in the vehicle stock sub-model, which itself has a 'closed' feedback effect. The lack of endogenous feedback effects is a significant weakness of the model given that for many policy options feedback effects may significantly reinforce or negate the initial effects.
- The aggregate total emissions produced by this 'distributional' model do not exactly match the estimated aggregate total emissions produced by an aggregate model, although the size of the discrepancy is accounted for within the model (see BTCE 1996e, appendix IV for a discussion of model calibration).

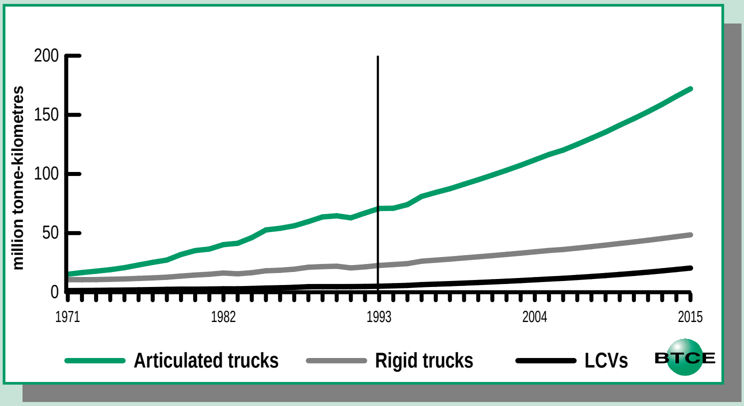
- The split of average VKT and average fuel efficiency by vehicle age are based on 1991 estimates. At present the split is assumed constant to 2015.
- Total fuel consumption by fuel type is calculated by apportioning total fuel consumption by fuel type. This approach was adopted because of a lack of information about the number of vehicles by fuel type, and also to maintain the ease of use of the model. A more satisfactory method of estimating fuel usage would be to allocate vehicles according to fuel type, and estimate total fuel consumption by fuel type.
- The scrapping function is assumed to be the same for different vehicle vintages. There is no in-built adjustment in the scrapping function to allow for more recent vintages being more durable, in contrast to the BTCE CARMOD (BTCE 1996a), where changes in vehicle durability by vintage are allowed for in the scrapping rates.

FIGURE VIII.4 ACTUAL AND PROJECTED SHARE OF THE TOTAL AUSTRALIAN ROAD FREIGHT TASK BY VEHICLE TYPE, 1971 TO 2015



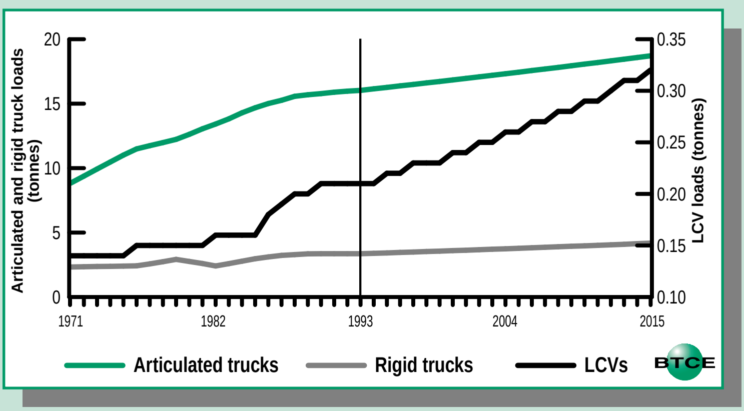
Source BTCE estimates.

FIGURE VIII.5 ACTUAL AND PROJECTED AUSTRALIAN ROAD FREIGHT TASK BY VEHICLE TYPE, 1971 TO 1995



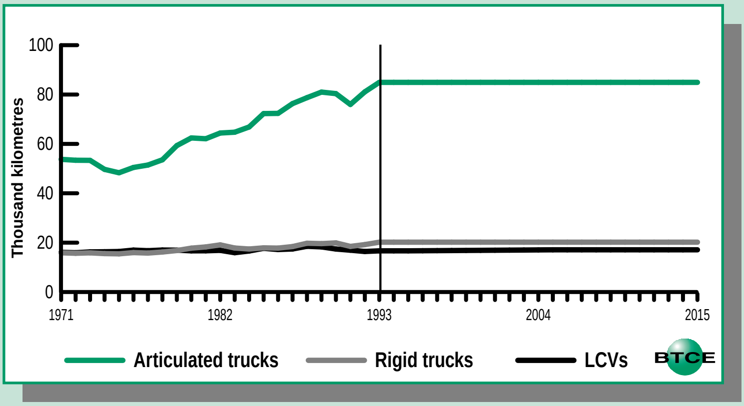
Source BTCE estimates.

FIGURE VIII.6 ACTUAL AND PROJECTED AVERAGE LOAD BY VEHICLE TYPE, 1971 TO 2015



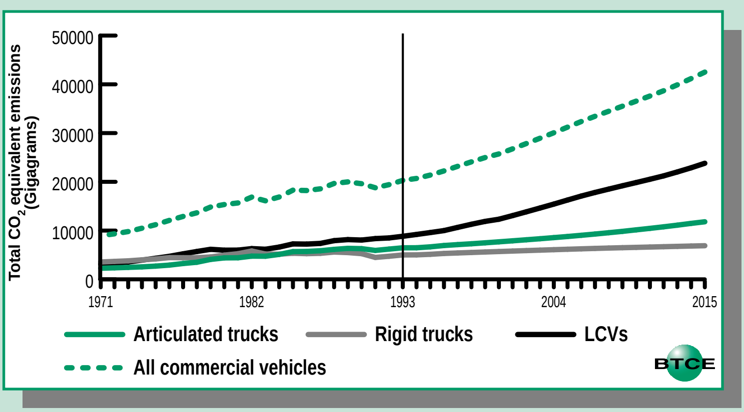
Source BTCE estimates.

FIGURE VIII.7 ACTUAL AND PROJECTED AVERAGE VEHICLE-KILOMETRES TRAVELLED BY VEHICLE TYPE, 1971 TO 2015



Source BTCE estimates.

FIGURE VIII.8 BASE CASE EMISSION PROJECTIONS BY VEHICLE TYPE, 1971 TO 2015



Source BTCE estimates.

APPENDIX IX AVMOD—BTCE MODEL OF THE SCHEDULED AUSTRALIAN DOMESTIC AIRCRAFT FLEET

Estimates of CO_2 equivalent emissions for domestic aviation were derived using AVMOD, a spreadsheet model of the Australian domestic scheduled aircraft fleet. AVMOD was constructed to analyse the impact of more fuel-efficient aircraft technology.

Domestic scheduled aircraft are taken generally to mean those that are used to provide regular services on the basis of published schedule on major routes. The model has three major inputs, projections of the size and composition of the aircraft fleet for each year to 2015, the fuel efficiency assumed for the aircraft, and average aircraft utilisation. These inputs are used to project CO_2 equivalent emissions for domestic aviation for each year from 1996 to 2015.

COMPOSITION OF THE DOMESTIC AVIATION FLEET

The composition of the aircraft fleet, in terms of number and type of aircraft, influences total fuel consumption and hence the level of CO_2 equivalent emissions. The domestic fleet currently comprises 120 aircraft manufactured by four different companies: Airbus, Boeing, British Aerospace, and Fokker (DOTC 1993). Airbus accounts for 14.2 per cent, Boeing 60 per cent, British Aerospace 15 per cent, and Fokker 10.8 per cent of the Australian domestic aircraft fleet (Pratt 1996, pp. 1–3). The number of seats per aircraft for aircraft used for domestic services ranges from 46 to 240. Seats per aircraft average 128 over the current Australian domestic fleet.

AVMOD allows simulation of the future composition of the fleet by applying the following three simple rules regarding the turnover of aircraft:

(1) The demand for domestic air passenger services (measured in passenger kilometres) determines the number of aircraft required in the fleet.

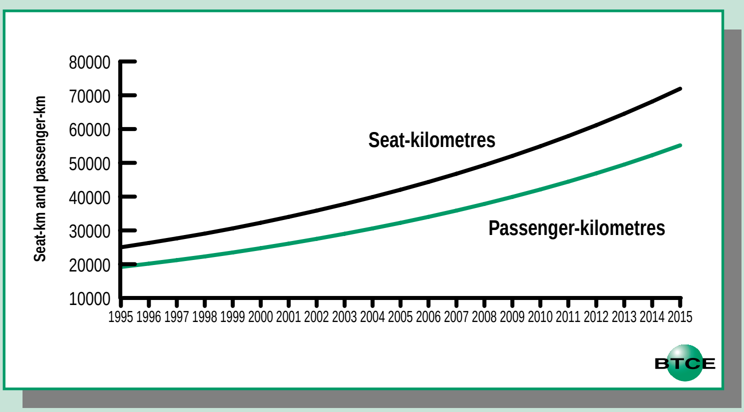
(2) Aircraft that have reached retirement age (greater than 20 years old) are replaced by aircraft of a similar or slightly larger size. The replacement of some aircraft retirements by slightly larger size provides for some of the required growth in the number of seats in the aircraft fleet.

(3) Additional larger aircraft are added to the fleet, to meet total passenger demand, such that the proportion of larger sized aircraft increases, but the number of smaller aircraft increase in absolute terms.

These three assumptions mean that the average size of aircraft in the fleet (measured as seats per aircraft) increases.

Projected future passenger demand (revenue passenger-kilometres) was based on an assumed growth rate of 5.4 per cent per annum (BTCE 1995c, p. 232). Under this assumption, passenger seat-kilometres increased from 25 005 million in 1995 to 71 948 million in 2015 (figure IX.1).

FIGURE IX.1 PROJECTED DOMESTIC AVIATION PASSENGER DEMAND AND SEAT SUPPLY, 1995 TO 2015



Source BTCE 1995c, p. 232.

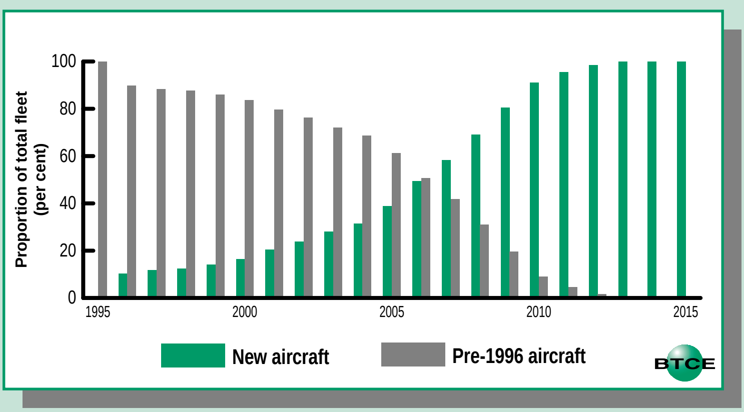
Replacement of aircraft

Given the level of available seat-kilometres of the existing fleet, extra aircraft are required to meet growth in passenger seat-kilometres. The number of aircraft required was assumed to be provided through the replacement of retired aircraft and the acquisition of additional aircraft to cater for the growth in passenger demand.

The replacement of aircraft was based on the retirement of aircraft from the AVMOD fleet after they reach 20 years in operation. Aircraft such as F50, BAe146-100, BAe146-200, BAe146-300, A300, and A320-200 were replaced with similar types except for A737-300 (replaced with B737 700), B737-400 (replaced with B737-800), and B767-200 (replaced with B767 300). Replacement aircraft generally have more seats than aircraft in the existing fleet, resulting in an increase in the average number of seats per aircraft to 182 by 2015. Aircraft such as the F28-1000 and F28-3000, and the F28-4000 and B727-200, were assumed to be phased out of the existing fleet in 1996 and 1997, respectively.

As a whole, the combination of replacement and additional aircraft yields a total number of 206 aircraft in the fleet by 2015. Under the aircraft scrapping assumptions, aircraft that are currently in the Australian domestic fleet in 1995 are all retired from the fleet by 2015 (figure IX.2).

FIGURE IX.2 PROJECTED COMPOSITION OF DOMESTIC SCHEDULED AIRCRAFT FLEET, 1995 TO 2015



Source BTCE estimates.

FUEL CONSUMPTION

It is well established in the literature (e.g. Greene 1992; Somerville 1993) that fuel consumption by aircraft is a complex product of factors such as weather conditions, airport traffic, and the operating characteristics of specific aircraft. Due to a shortage of information on the first two factors, estimates of fuel consumption were limited to the operating characteristics of aircraft. The resulting fuel consumption was derived using the following equation (Greene 1992, p. 563):

$$E_i = \frac{A_i \times H_i \times V_i \times S_i}{(\text{skm} / L)_i} \tag{1}$$

where E_i is litres of avtur use by aircraft type i; A_i is number of aircraft of type i; H_i is average aircraft utilisation (hours flown per year) per aircraft of type i; V_i is mean block speed per aircraft of type i; S_i is number of seats per aircraft of type i; and skm/L_i is seat-kilometres per litre of avtur for aircraft of type i.

Assumptions

Projection of aviation turbine fuel consumption to the year 2015 required assumptions about the rate of technology penetration, fuel efficiency, and the operating characteristics of various aircraft.

- Under the basecase it was assumed that new aircraft that enter the fleet utilise 1990s technology. Fleet average fuel efficiency improves because the new aircraft are more fuel efficient than the aircraft that they replace, and because of an increase in the average size of aircraft. Two alternative technology scenarios were analysed using AVMOD, a high fuel efficiency and a low fuel efficiency improvement as a result of the introduction of new aircraft technology (see table 13.4 in chapter 13). Under the low fuel efficiency scenario it was assumed that new generation aircraft introduced into the fleet between 2005 and 2009 would be 20 per cent more fuel efficient than the comparable 1990s generation aircraft they replace, aircraft introduced into the fleet between 2010 and 2014 would be 30 per cent more fuel efficient, and by 2015 new generation aircraft would be 45 per cent more fuel efficient than the comparable 1990s generation aircraft. Under the high efficiency technology scenario it was assumed that new generation aircraft are to be introduced into the fleet as per the low efficiency scenario, with aircraft introduced between 2005 and 2009 being 20 per cent more fuel efficient than comparable 1990s generation aircraft, and aircraft introduced from 2010 onwards are assumed to be 70 per cent more fuel efficient than 1990s generation aircraft.

- Average passenger load factors were assumed to remain constant at 77 per cent over the study period of 1996 to 2015, mainly because of a lack of better information about future trends. Greene (1992, p. 539) states that there is a school of thought that suggests that there is a ceiling on US domestic load factors because of the inconvenience to air travellers of overbooking and increased circuitousness caused by hubbing.
- A number of simplifications have been made for mean block speed and average aircraft utilisation (hours flown per year) of new model aircraft. These two characteristics were assumed to remain constant in the basecase scenario. In the post-2000 technology scenarios, mean block speed and average aircraft utilisation of new models were assumed to have the annual average of the same class based on models from the 1990s (Greene 1992, p. 564). For example, B747-2/300 and B747-400 were assumed to have the same mean block speed and average aircraft utilisation as the B767-200.
- The fuel efficiencies of new models are based on the same class as that available in the existing fleet. But this is an oversimplification of a rather complex issue, and it is likely that there is some underestimation of fuel efficiencies of new aircraft.

Data

Data on the number of aircraft, mean block speed and average aircraft utilisation were taken from DOTC (1993, p. 27). Seats per aircraft of existing aircraft and new aircraft models for later years were taken from DOTC (1993, p. 24) and *Aviation Week & Space Technology* (1996, pp. 50–52), respectively. Due to the lack of information from the aircraft industry, the fuel intensities (in seat-kilometres per litre) of existing aircraft types were based on BTCE (1992a, p. 76).

PROJECTED FUEL CONSUMPTION

Using equation (1) and the assumptions about the characteristics of aircraft operations detailed above, total aviation fuel consumption under the basecase was projected to grow at a rate of 3.8 per cent per annum, with avtur consumption increasing from 1593 million litres in 1995 to

3386 million litres in 2015. The growth rates for the low fuel efficiency and high fuel efficiency scenarios were 3.6 per cent and 3.4 per cent, respectively. Table IX.1 lists total fuel consumption under the alternative aircraft technology scenarios.

PROJECTED EMISSIONS

Total emissions from aircraft depend on engine technology and the type and amount of fuel consumed (BTCE 1992a, p. 62). AVMOD was used to estimate total fuel consumption in litres. To derive total emissions, fuel consumption was converted into energy use by applying the energy density of avtur, which is equivalent to 36.8 megajoules per litre (BTCE 1995c, p. 77).

TABLE IX.1 TOTAL DOMESTIC AVTUR CONSUMPTION UNDER ALTERNATIVE AIRCRAFT TECHNOLOGY SCENARIOS

(megalitres)

Year	*Base case*	*Low efficiency*[a]	*High efficiency*
1995	1 592.8	1 592.8	1 592.8
1996	1 652.8	1 652.8	1 652.8
1997	1 714.6	1 714.6	1 714.6
1998	1 778.3	1 778.3	1 778.3
1999	1 847.3	1 847.3	1 847.3
2000	1 920.7	1 920.7	1 920.7
2001	1 996.6	1 996.6	1 996.6
2002	2 075.3	2 075.3	2 075.3
2003	2 156.9	2 156.9	2 156.9
2004	2 241.4	2 241.4	2 241.4
2005	2 328.5	2 324.9	2 324.9
2006	2 418.7	2 414.7	2 414.7
2007	2 512.1	2 509.5	2 509.5
2008	2 608.9	2 600.5	2 600.5
2009	2 709.2	2 689.2	2 689.2
2010	2 812.4	2 777.0	2 720.5
2011	2 919.3	2 866.7	2 777.6
2012	3 030.0	2 955.8	2 843.6
2013	3 144.6	3 046.3	2 909.7
2014	3 263.2	3 142.6	2 988.3
2015	3 385.9	3 240.1	3 088.2

a. Assumptions given in table 13.4 in chapter 13.

Source BTCE estimates.

To simplify the analysis, it was assumed that the fuel efficiency improvement in avgas powered aircraft would be equal to the fuel efficiency improvement of avtur powered aircraft. The BTCE considered this a reasonable assumption given that avgas powered aircraft contribute only 5 per cent of total greenhouse gas emissions from domestic aviation.

Aircraft emissions were estimated by applying the appropriate emissions factor to total avtur energy use. Greenhouse gas emissions measured by CO_2 equivalent were then derived by multiplying these emissions by their global warming potential. Appendix IV lists the emissions factors and corresponding global warming potential of each type of gas emitted by aircraft. The projected level of emissions under alternative technology scenarios are given in table IX.2.

TABLE IX.2 TOTAL CO_2 EQUIVALENT EMISSIONS FROM DOMESTIC AVTUR CONSUMPTION UNDER ALTERNATIVE AIRCRAFT TECHNOLOGY SCENARIOS

(thousand tonnes)

Year	*Base case*	*Low efficiency*[a]	*High efficiency*
1995	4149.1	4149.1	4149.1
1996	4305.4	4305.4	4305.4
1997	4466.4	4466.4	4466.4
1998	4632.2	4632.2	4632.2
1999	4812.0	4812.0	4812.0
2000	5003.1	5003.1	5003.1
2001	5201.1	5201.1	5201.1
2002	5406.1	5406.1	5406.1
2003	5618.5	5618.5	5618.5
2004	5838.6	5838.6	5838.6
2005	6065.5	6056.3	6056.3
2006	6300.5	6290.1	6290.1
2007	6543.9	6537.0	6537.0
2008	6796.1	6774.0	6774.0
2009	7057.3	7005.1	7005.1
2010	7326.2	7233.7	7086.6
2011	7604.6	7467.5	7235.3
2012	7892.9	7699.5	7407.5
2013	8191.3	7935.4	7579.7
2014	8500.3	8186.2	7784.3
2015	8820.1	8440.3	8044.4

a. Assumptions given in table 13.4 in chapter 13.

AIRCRAFT TECHNOLOGY ASSUMPTIONS

The energy efficiency gains assumed for the post-2000 scenario are possible through technological improvements to engine propulsion systems, aircraft airframes, and development of larger size aircraft. This section presents an outline of the main aircraft technology possibilities described by Greene (1992), Sweetman (1984), Albers and Zuk (1988), Ruffles (1993) and Stryker (1993).

Propulsion

Since its introduction in commercial aircraft in the 1960s, the jet engine has evolved from turbojet to turbofan to high-bypass turbofan, with a 40 per cent increase in energy efficiency over that period. High-bypass turbofan engines currently in use achieve greater propulsion by sending 5 to 6 times as much air around the core to be accelerated by the fans driven by the core turbine engine. The result is greater thrust per unit of fuel consumed.

A major propulsion advance can be realised with ultra high-bypass (UHB) engines that boost the bypass ratio up to 2 to 3 times current levels. Ducted UHB turbofans have been shown to yield efficiency improvements of 10–20 per cent. Unducted, or propfan, engines using eight or more highly swept blades, have been demonstrated to achieve 20–30 per cent efficiency increases over the best current turbofan engines.

Advanced propeller designs, some using twin counter-rotating propellers, have overcome the previous speed limitation of turboprops, enabling aircraft to achieve Mach 0.6 to 0.85 with propfans. Advanced unducted propeller designs deliver 30 per cent greater fuel economy but cost twice as much (US$10 million compared to US$5 million for a US$30–40 million aircraft) as present generation high-bypass engines. Concerns about noise, vibration, and maintenance have prevented their acceptance in the marketplace.

Improvements in the thermodynamic efficiency of the turbine depend directly on the development of advanced, high temperature materials. Advanced ceramic and metal matrix composite materials will be necessary to raise turbine inlet temperatures by 250°C to increase engine efficiency by 20 per cent.

Airframe

Future airframe efficiency improvements will require reductions in aerodynamic drag and airframe weight. Advances in the computational modelling of fluid dynamics will lead to greater optimisation of aerodynamic designs.

At low speeds, airflow over a wing takes place in smooth layers (laminar flow). As speeds increase, a greater percentage of this airflow becomes turbulent, increasing drag. Research into reducing aerodynamic drag is progressing in three main ways:

- natural laminar flow (NLF) concepts which are attempts to design smooth shapes to minimise drag;
- laminar flow control (LFC) concepts which attempt to actively minimise drag through changed wing shapes according to speed, altitude and weight; and
- hybrid laminar flow (HLF) concepts that include grooves or small holes through which part of the air flows to reduce turbulence.

An early version of a HLF concept achieved a 5 to 10 per cent drag reduction on a Boeing 757 aircraft (Greene 1992, p. 550).

Lightweight composite materials have the potential to reduce airframe weight by up to 30 per cent, without compromising the structural strength of the aircraft. Lighter airframes require smaller engines, and these two effects would reduce the amount of fuel load required, further reducing the weight. Greene (1992, p. 551) reports elasticities of fuel use with respect to aircraft weight of 0.75 for large aircraft down to 0.38 for lighter aircraft. Based on these results, Greene estimates that a 30 per cent reduction in airframe weight should reduce fuel consumption by 7–15 per cent under operating conditions.

Operations

There is a trend towards the use of larger aircraft, driven by increasing demand for air travel and reduction in the average per passenger operating costs of airlines, for stage lengths above a certain distance. Greene (1992, p. 551) states that aircraft manufacturers expect the demand for aircraft with less than 170 seats to stagnate, while demand for larger aircraft will increase. The trend towards larger aircraft will improve fleet average (per passenger-kilometre) fuel efficiency.

Very large aircraft designs, seating 600 to 800 passengers, are on the drawing board but there is no firm intention to introduce them in the foreseeable future.

Greater airport congestion has the potential to reduce fuel efficiency, as take-off and landing delays will increase total fuel use. Greene (1992, p. 552) cites some evidence that improved flight planning could reduce fuel use by 6 per cent.

Super and hypersonic aircraft

Greene (1992, p. 552) states that supersonic air travel could capture an increasing share of passenger aviation services by 2010. Research and development in the area of supersonic aviation could also generate improvements in subsonic aircraft. For supersonic aircraft, aerodynamics are even more critical than for subsonic aircraft. But aerodynamic drag at higher speeds is not the only problem that researchers face. The ability of wings and engine materials to withstand higher temperatures is also a constraint. The thermal stability of fuel is also a factor at higher speeds. Greene (1992, p. 552) states that at speeds around Mach 8, hydrogen's high reaction rate, and its ability to serve as a heat sink for the engine, may make it the only technologically viable fuel.

It has been assumed that supersonic air travel will not be used for regular domestic air services in Australia between 1996 and 2015. Greene (1992, p. 553) states that 'subsonic engine [aircraft] ... will continue to dominate commercial air travel', at least until 2010.

Overall fuel efficiency improvement

Ultra high-bypass and propfan engines are mutually exclusive technologies. Propfan engines are currently limited in the amount of thrust that they can generate due to physical constraints on the size of the external fan. Until this limitation can be overcome they will be limited to narrow-body aircraft, or to wide-body aircraft with more than two engines. Greene (1992, p. 553) estimates the median seat-miles per gallon improvement of 83 per cent for propfans and 70 per cent for ultra high-bypass engines. Recent work by Greene (1995) suggests the fuel efficiency improvements outlined in Greene (1992) may be slightly optimistic and that the fuel efficiency improvement available from new technology for jet aircraft is more likely to be in the range of around 40 per cent by 2015. Table IX.3 provides a summary of estimates of the likely fuel efficiency

TABLE IX.3 ESTIMATED EFFECTIVENESS OF FUEL EFFICIENCY TECHNOLOGY FOR NEW PASSENGER AIRCRAFT

(per cent improvement in fuel efficiency)

Study	*Date of introduction*	*Propulsion technology*	*Advanced aerodynamics*	*Weight reduction*	*Total fuel efficiency improvement*
Greene (1992)	By 2005	27.5 37.5 Propfans	27.0	15.0	69.5 8
NRC (1992)	1995–2015	25	15[a]		40
NASA Lewis Research Center goals	By 2005 By 2015	 30	 10	 5	15–20 45
Greene (1995)	1995–2015: ‘Low efficiency’ scenario ‘High efficiency’ scenario				 15 (= 0.7 per cent pa) 64 (= 2.5 per cent pa)

a. A 15 per cent fuel efficiency improvement due to advanced aerodynamics and weight reduction.

Source Greene 1995.

improvement from new technology. The National Research Council (1992) report estimated that a reasonable goal for the next two decades was an improvement of about 40 per cent in fuel consumption per seat. The NASA Lewis Research Center set efficiency goals for 2015 of a 30 per cent fuel efficiency improvement from propulsion technology, a 10 per cent improvement from advanced aerodynamics, and a 5 per cent improvement from weight reduction (Greene, 1995 pp. 4–5). The estimates used in the analysis in **chapter 13** are based on NASA's efficiency goals.

APPENDIX X SOCIAL COSTS OF ACCIDENTS AND NOXIOUS EMISSIONS

Environmental costs of noxious emissions

Average damage costs were derived for Australian vehicle emissions (in dollars per kilogram emitted) by reviewing the Australian and international literature on the costs associated with air pollution (table X.1).

The unit damage costs in table X.1 are very approximate, and should be treated as likely order of magnitude values only. Due to the difficulty in estimating such costs, values reported in the literature vary by more than a factor of 100, particularly because the exact effects of air pollution on humans and on the natural environment are still largely unknown.

Two of the more thorough Australian studies have been prepared for the Environment Protection Authority of Victoria (Chestnut et al. 1994) and the National Road Transport Commission (Segal 1995). The values derived for NMVOCs and particulates in table X.1 are mainly based on data from these two studies. However, costs for emissions of oxides of nitrogen (NO_x) other than nitrous oxide, sulphur oxides (SO_x) and carbon monoxide (CO) were not included in the Environment Protection Authority of Victoria or the National Road Transport Commission analyses due to concentrations of these gases currently being below recommended acceptable levels for all Australian cities. Approximate costs were therefore estimated by reviewing the international literature.

Using the values in table X.1 and average emission rates for Australian road vehicles yielded an estimate of 0.11 cents per kilometre (with a likely range of 0.02–0.35) as the average cost to society from noxious emissions generated by the Australian motor vehicle fleet. This figure has been used throughout the Report as part of the estimate of social costs where greenhouse abatement measures result in changes in noxious emissions from road vehicles.

TABLE X.1 SYNTHESISED ESTIMATES OF UNIT COSTS OF ENVIRONMENTAL DAMAGE FROM AIRBORNE POLLUTANTS

($/kg)

Sector	*NO_X and NMVOCs*	*CO*	*SO_X*	*Particulates*
Major urban				
Average	0.07	0.002	0.01	12.50
Likely range	0.01–0.70	0.0–0.02	0.0–0.45	3–18
Other				
Average	0.02	0.0	0.0	0.0
Likely range	0.0–0.23			

Notes
1. Costs are in 1996 Australian dollars (per kilogram of gas emitted).
2. Environmental effects of air pollution include health losses (morbidity and mortality), soiling and corrosion, vegetation damage and impaired visibility. The major component of the above costs is due to health effects.
3. ‘Major urban’ refers to emissions in Sydney, Melbourne, and the central areas of the other capital cities. ‘Other’ is provincial urban and non-urban, and is based on the relative differences between urban and rural costs given in the international literature. Weighting by area of travel, with 57 per cent of kilometres travelled by light duty vehicles in Australia being within capital cities (ABS 1993a, p.13), gives rough national averages of $0.05 per kg for NO_X and NMVOCs, and $0.001 per kg for CO.
4. The main difference between the lower value for particulate matter ($3/kg, derived using Segal 1995) and the upper value ($18/kg, derived using Chestnut et al. 1994), is the values attached to the loss of life. Segal assumes a value of $1 million per life (as the cost of premature death from respiratory illness or cancer), while Chestnut et al. assume $5 million.
5. Values given for NO_X and NMVOCs are partly based on the assumption that the rate of formation of urban ozone is proportional to the sum of NO_X and NMVOC emissions. This is very approximate, since ozone levels depend non-linearly on ambient concentrations of NO_X, CO and NMVOCs, and are sensitive to meteorological conditions.
6. A cost of 0.0 means assumed negligible.

Sources Segal 1995; Chestnut et al. 1994; Cosgrove et al. 1994; Miller & Moffet 1993; RCNPT 1992; Quinet 1994; Sinclair Knight 1993; Litman 1994.

Segal (1995) derived an estimate of 0.03 cents per kilometre (with a likely range of 0.005–0.12) as the health cost of Australian motor vehicle emissions (note 4 to table X.1).

Rates derived for overseas cities with higher levels of air pollution than is common in Australia are typically much higher. Litman (1994), for example, in reviewing various US studies, estimates an average of around 4 cents per kilometre for damage costs due to air pollution.

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(Litman derives costs of about \$6 per kg for SO_x and \$4 per kg for NO_x.) If expenditure on emission control equipment in current new cars were viewed as indicative of American society's willingness to pay for emission reductions, values of the order of \$1 per kg for hydrocarbon emissions and 10 cents per kg for CO emissions could be implied.

SOCIAL COSTS OF ACCIDENTS

Greenhouse abatement measures that affect distances travelled (measured in vehicle-kilometres travelled) will affect not only the level of noxious emissions, but also the number of crashes (accidents). In assessing an abatement measure it is therefore necessary to take account of any consequential changes in the costs of crashes to the community.

It can be argued that an increase in the level of traffic will increase the exposure of each vehicle to the risk of a crash. On the other hand, it has been claimed that drivers adjust to changes in risk so that overall risk of crashes reduces or remains the same (BTCE 1995h, pp. 259–263). If true, these concepts of 'risk compensation' and 'risk homeostasis' would suggest that the overall number of crashes will not change significantly with different traffic conditions or congestion levels.

However, it is the change in the cost of crashes (rather than their number) that needs to be taken into account in evaluating greenhouse abatement measures. While the issue is complex and would require substantial empirical research, it was assumed implicitly that increased urban congestion would not increase the cost of crashes. In conditions of increased and slower traffic, the number of crashes involving minor or nil injury is likely to rise, whereas the number of crashes involving fatalities would fall. The 'human capital' methodology used to value road crashes is discussed in BTCE (1992b, ch. 3).

An approximate per kilometre cost of road crashes was estimated using data on the social cost of road crashes (\$6.1 billion in 1993) (BTCE 1994d). Dividing by the 163 billion kilometres travelled in that year by cars, trucks and light commercial road vehicles (BTCE 1995c, appendix VIII) yields an estimate of about 4 cents per kilometre travelled.

The estimate of per kilometre crash cost is very rough, partly because of its nature as an average, and partly because the cost of road crashes in 1993 includes vehicles such as motorcycles and buses, while the figure for kilometres travelled does not. It also does not take into account the fact that the number of fatalities on Australian roads is trending downwards over time, or the potentially beneficial effect of new technology such as anti-lock braking systems or air bags.

APPENDIX XI CHRONOLOGICAL LIST OF BTCE PUBLICATIONS ON GREENHOUSE AND RELATED ISSUES

BTCE 1990, 'Transport and the greenhouse effect', *Transport and Communications Indicators*, AGPS, Canberra, March Quarter, pp. 1, 16–18.

BTCE 1991, *Greenhouse Gas Emissions in Australian Transport*, Working Paper 1, BTCE, Canberra.

BTCE 1991, 'Greenhouse gas emissions in Australian transport', *Transport and Communications Indicators*, AGPS, Canberra, September Quarter, pp. 1, 20.

BTCE 1991, *Reducing Greenhouse Gas Emissions in Transport: Some Tax Policy Options*, Working Paper 3, BTCE, Canberra.

BTCE 1992, *Fuel Efficiency of Ships and Aircraft*, Working Paper 4, BTCE, Canberra.

BTCE 1993, 'Goods and bads in urban transport', *Transport and Communications Indicators*, AGPS, Canberra, September Quarter, pp. 1, 19–20.

BTCE 1993, *Costs of Reducing Greenhouse Gases in Australian Transport*, Working Paper 10, BTCE, Canberra.

BTCE 1993, 'Alternative fuels', *Transport and Communications Indicators*, AGPS, Canberra, December quarter, pp. 1, 23–27.

Hensher, D.A. 1993, *Greenhouse Gas Emissions and the Demand for Urban Passenger Transport: Design of the Overall Approach*, BTCE Occasional Paper 108, BTCE, Canberra.

Young, W. 1993, *Modelling the Land Use–Transport–Environment Interaction*, BTCE Occasional Paper 107, AGPS, Canberra.

BTCE 1994, *Alternative Fuels in Australian Transport*, BTCE Information Paper 39, AGPS, Canberra.

National Greenhouse Gas Inventory Committee (NGGIC) 1994, *Energy: Workbook for Transport (Mobile Sources),* ed. Working Party chaired by BTCE, NGGIC Workbook 3.0 1994, Part of *National Greenhouse Gas Inventory 1988 and 1990,* DEST, Canberra.

BTCE 1995, *Greenhouse Gas Emissions from Australian Transport: Long-term Projections*, Report 88, AGPS, Canberra.

BTCE 1995, *Urban Congestion: Modelling Traffic Patterns, Delays and Optimal Tolls*, Working Paper 15, BTCE, Canberra.

Dobes, L. 1995, *Greenhouse Gas Emissions in Australian Transport in 1900 and 2000*, BTCE Occasional Paper 110, BTCE, Canberra.

BTCE 1996, *Traffic Congestion and Road User Charges in Australian Cities*, Report 92, AGPS, Canberra.

BTCE 1996, *Costs of Reducing Greenhouse Gas Emissions from Australian Road Freight Vehicles: An Application of the BTCE TRUCKMOD Model*, Working Paper 22, BTCE, Canberra.

BTCE 1996, *Trees and Greenhouse: Costs of Sequestering Australian Transport Emissions*, Working Paper 23, BTCE, Canberra.

BTCE 1996, *Costs of Reducing Greenhouse Gas Emissions from Australian Cars: An Application of the BTCE CARMOD Model*, Working Paper 24, BTCE, Canberra.

BTCE 1996, *Costs of Reducing Greenhouse Gas Emissions from the Australian Transport Sector*, BTCE Report 94, AGPS, Canberra.

APPENDIX XII SHIFTING INTERCAPITAL FREIGHT FROM ROAD TO RAIL: MODELLING FUEL AND EMISSION CHANGES

Evaluation of the greenhouse gas effects of a measure to shift intercapital freight from road to rail requires estimates of basecase tonnages, tonnages shifted, fuel use changes and emission changes.

Modelling rail tonnages

Basecase intercapital rail freight was modelled as a function of Australian real gross non-farm product (RGNF) and capacity utilisation.

A measure of production in Australia, RGNF was chosen because it does not include farm production (which consists predominantly of bulk commodities) and because it probably better reflects movements in non-bulk inter-city freight. As the level of production increases, rail tonnages should also increase, so that RGNF will have a positive coefficient.

Capacity utilisation was measured as the number of firms reporting that they are operating above normal capacity, less the number of firms reporting they are operating below normal capacity (ACCI-Westpac 1996). When capacity utilisation is high, Australian firms experience difficulty in meeting demand and imports tend to rise. When imports are unloaded they are transported by both road and rail to other areas in Australia. A rise in imports can thus be expected to increase non-bulk tonnages carried by rail on the six major corridors. Consequently, capacity utilisation can be expected to possess a positive coefficient.

The intercapital rail freight equation was estimated (using data from 1971–72 to 1994–95) to be:

$$\underset{}{\ln RLFRT} = \underset{(0.59)}{-7.60} + \underset{(0.05)}{0.75} \ln RGNF + \underset{(0.0003)}{0.002}\, CAPUT + \underset{(0.02)}{0.12}\, SDUM - \underset{(0.03)}{0.14}\, AMDUM \qquad (1.0)$$

$\overline{R}^2 = 0.98$ DW=2.0

where:

( ) is standard error;

RLFRT is sum of the non-bulk tonnages carried by rail on the six major intercapital corridors;

RGNF is Australian real gross non-farm product;

CAPUT is capacity utilisation (ACCI-Westpac index);

SDUM is a dummy variable to account for the introduction of rail superfreighters: 1971–72 to 1987–88=0 and 1988–89 to 1994–95=1;

AMDUM is a dummy variable to account for the closure of the Adelaide–Melbourne line for upgrading to standard gauge: 1994–95 = 1; otherwise = 0;

ln is the natural logarithm.

The fit of the equation is good, with RGNF, CAPUT, SDUM and AMDUM explaining 98 per cent of the variation in RLFRT. There is no evidence of serial correlation and all variables are statistically significant with coefficients having the expected sign.

Projecting aggregate base case rail tonnages

Basecase projections of aggregate intercapital rail freight to 2015 were obtained on the basis of a number of assumptions:

- RGNF was assumed to increase at 3.2 per cent per annum from 1995–96 to 1997–98 and 3.3 per cent per annum from 1998–99 to 2014–15 (BTCE 1995c, p. 55).
- Capacity utilisation (CAPUT) was assumed to equal –35 in 1995–96, reflecting a slowdown in the Australian economy. From 1996–97 to 2014–15, it was assumed to equal –27, which is the historical average value when the economy is growing at a normal rate (that is, the economy is experiencing neither a boom nor a recession).

- It was assumed that superfreighters will continue to operate into the future, so that SDUM was set at 1 from 1995–96 to 2014–15. The Adelaide–Melbourne corridor was assumed to remain open, so AMDUM was set to zero from 1995–96 to 2014–15.

Resulting basecase projections of intercapital rail freight are shown in table XII.1. The projected basecase tonnage growth is about 2.5 per cent per year. Starting from about 8 million tonnes a year in 1994–95, intercapital rail freight is projected to grow to about 13 million tonnes a year by 2015.

Projecting corridor-by-corridor basecase rail tonnages

Because evaluation was based on a corridor-by-corridor approach, aggregate rail tonnage projections were disaggregated, with data expressed as either an origin–destination tonnage or link tonnage. Origin–destination tonnages are those carried from an origin to a destination. Sydney–Melbourne origin–destination tonnages are carried from Sydney to Melbourne and from Melbourne to Sydney. Link tonnages are the number of tonnes carried along a particular corridor. Link tonnages for Sydney–Melbourne would be the sum of the Sydney–Melbourne, Brisbane–Melbourne, Adelaide–Sydney, Adelaide–Brisbane, Brisbane–Perth and Sydney–Perth origin–destination tonnages (both ways).

Link tonnages were used to project basecase corridor rail freight in two stages. Link tonnages were calculated for 1990–91, based on ABS (1992d) origin–destination rail freight data (table XII.2).

The annual growth rate of 2.5 per cent per year from the aggregate projections model was applied to table XII.2 to generate corridor-by-corridor basecase tonnage estimates for 1995–96 to 2014–15.

Estimation of tonnages diverted to rail

The amount of intercapital road freight assumed to be diverted to rail by 2015 on each of the corridors was based on work done by the BTCE for the National Transport Planning Taskforce (NTPT) and published in BTCE (1995a, pp. 59–61). These tonnages are shown in table XII.3, along with projected basecase tonnages in 2015.

TABLE XII.1 BASECASE DATA FOR PROJECTING RAIL TONNAGES

Year ending June	*RLFRT (Mt)*	*RGNF ($ million)*	*CAPUT*	*Fuel intensity road (MJ/tonne-km)*	*Fuel intensity rail (MJ/tonne-km)*
1972	3.95	196 044	–29.25	1.854	na
1973	4.48	206 093	–7.00	1.797	na
1974	4.82	215 246	14.00	1.750	na
1975	4.42	219 039	–41.25	1.704	na
1976	4.52	224 786	–48.50	1.651	na
1977	4.71	232 171	–42.00	1.677	na
1978	4.49	234 455	–39.50	1.679	0.79
1979	4.80	245 943	–23.50	1.670	0.76
1980	5.22	253 911	–12.00	1.629	0.74
1981	5.30	264 072	–10.25	1.579	0.71
1982	5.70	270 796	–18.00	1.541	0.71
1983	4.63	266 315	–59.25	1.495	0.70
1984	5.20	277 172	–32.50	1.445	0.70
1985	5.42	292 450	–19.00	1.408	0.70
1986	5.80	305 144	–10.75	1.381	0.66
1987	6.05	311 970	–19.00	1.362	0.62
1988	6.39	330 040	–4.50	1.342	0.58
1989	7.42	345 031	8.25	1.302	0.56
1990	7.31	356 276	–26.00	1.270	0.55
1991	6.75	351 926	–62.75	1.230	0.53
1992	6.68	354 625	–64.50	1.207	0.53
1993	7.08	365 204	–53.75	1.190	0.53
1994	7.74	380 612	–30.00	1.188	0.53
1995	7.24	403 539	–8.25	1.171	0.52
1996	8.08	418 896	–35.00	1.154	0.52
1997	8.41	432 301	–27.00	1.138	0.52
1998	8.61	446 134	–27.00	1.121	0.51
1999	8.82	460 857	–27.0.0	1.105	0.51
2000	9.03	476 065	–27.00	1.089	0.50
2001	9.25	491 775	–27.00	1.074	0.50
2002	9.48	508 004	–27.00	1.059	0.50
2003	9.71	524 768	–27.00	1.043	0.49
2004	9.95	542 085	–27.00	1.028	0.49
2005	10.19	559 974	–27.00	1.014	0.49
2006	10.44	578 453	–27.00	0.999	0.48
2007	10.70	597 542	–27.00	0.985	0.48
2008	10.96	617 261	–27.00	0.971	0.48
2009	11.23	637 631	–27.00	0.957	0.47
2010	11.50	658 672	–27.00	0.943	0.47
2011	11.78	680 409	–27.00	0.930	0.46
2012	12.07	702 862	–27.00	0.916	0.46
2013	12.36	726 057	–27.00	0.903	0.46
2014	12.67	750 016	–27.00	0.890	0.45
2015	12.98	774 767	–27.00	0.875	0.45

RLFRT Rail non-bulk tonnages on six inter-capital corridors
RGNF Real gross non-farm product
CAPUT Capacity utilisation

Sources BTCE 1995a *Indicators* database, 7 June 1995; BTCE estimates.

TABLE XII.2 1990–91 LINK RAIL TONNAGES

(Mt)

	Corridors			
Origin–destination pair	*Sydney–Melbourne*	*Sydney–Brisbane*	*Adelaide–Melbourne*	*Adelaide–Perth*
Sydney–Melbourne	1 421			
Sydney–Brisbane		1 520		
Sydney–Adelaide	395		395	
Sydney–Perth	521		521	521
Melbourne–Brisbane	557	557		
Melbourne–Adelaide			1 190	
Melbourne–Perth			572	572
Adelaide–Brisbane	147	147	147	
Adelaide–Perth				626
Brisbane–Perth	72	72	72	72
Total (link tonnage)	3 113	2 296	2 897	1 791

Sources ABS 1992d; BTCE estimates.

The time path of the 'after-investment' rail tonnages was estimated by taking into account the assumed infrastructure upgrades in the periods 1996–2000 and 2006–2010. Each upgrade was assumed to produce half the total tonnage shift estimated for the year 2015 in table XII.3. (The two upgrade stages were estimated to produce an equal 25 per cent reduction in travel time.) Thus the after-investment rail tonnage for the years 2000 and 2005 were the basecase tonnages plus half of the total change by 2015. Similarly, the after-investment tonnages for the years 2010 and 2015 were the basecase tonnages plus the full amount of the tonnages assumed diverted from road by the year 2015. The resulting time path of basecase and after-investment tonnages for each corridor are shown in table XII.3.

It should be noted that table XII.3 shows tonnages carried along each corridor if *all* corridors have been upgraded. But corridors could be expected to be upgraded sequentially. If all corridors are not upgraded together, and it is assumed that the tonnage along an origin–destination pair increases only when the *entire* route is upgraded, then only a proportion of the after-investment tonnages shown in table XII.3 will be attained. That proportion will increase as further corridors are upgraded and increasing network benefits are realised.

TABLE XII.3 TONNAGES CARRIED BY RAIL

(Mt)

Year ending June	Basecase link tonnages				After-investment link tonnages			
	Syd–Mel	Syd–Bris	Adel–Mel	Adel–Per	Syd–Mel	Syd–Bris	Adel–Mel	Adel–Per
1995	3.723	2.746	3.465	2.142	3.723	2.746	3.465	2.142
1996	3.815	2.814	3.551	2.195	4.034	2.922	3.856	2.220
1997	3.910	2.884	3.639	2.249	4.345	3.098	4.252	2.299
1998	4.006	2.955	3.729	2.305	4.657	3.273	4.646	2.377
1999	4.105	3.028	3.821	2.362	4.968	3.449	5.039	2.455
2000	4.207	3.103	3.916	2.421	5.279	3.625	5.433	2.534
2001	4.311	3.180	4.012	2.480	5.410	3.715	5.567	2.597
2002	4.418	3.259	4.112	2.542	5.544	3.807	5.705	2.661
2003	4.527	3.339	4.214	2.605	5.681	3.901	5.486	2.727
2004	4.639	3.422	4.318	2.669	5.821	3.997	5.991	2.794
2005	4.754	3.507	4.425	2.735	5.965	4.096	6.139	2.863
2006	4.872	3.593	4.534	2.803	6.219	4.249	6.441	2.945
2007	4.992	3.682	4.646	2.872	6.473	4.402	6.743	3.027
2008	5.116	3.773	4.761	2.943	6.727	4.555	7.045	3.109
2009	5.243	3.867	4.879	3.016	6.981	4.708	7.347	3.191
2010	5.372	3.963	5.000	3.091	7.234	4.861	7.649	3.273
2011	5.505	4.061	5.124	3.167	7.418	4.984	7.843	3.356
2012	5.642	4.161	5.251	3.246	7.606	5.111	8.042	3.441
2013	5.781	4.264	5.381	3.326	7.799	5.241	8.246	3.529
2014	5.924	4.370	5.514	3.408	7.997	5.374	8.455	3.618
2015	6.071	4.478	5.650	3.493	8.200	5.510	8.670	3.710

Sources ABS 1992d; BTCE 1995a; BTCE estimates.

For example, table XII.4 lists the origin–destination freight which travels along the Sydney–Melbourne corridor. If only the Sydney–Melbourne corridor is upgraded, then only Sydney–Melbourne origin–destination traffic is affected: 45.6 per cent of total freight on the Melbourne–Sydney link. Therefore, if only the Sydney–Melbourne corridor is upgraded, it is assumed that only 45.6 per cent of the total increase in freight implied by table XII.3 will be achieved in any given year.

Applying the same rationale to sequential upgradings yields the percentage achievement of NTPT tonnages shown in tables XII.5 and XII.6.

TABLE XII.4 UPGRADING THE SYDNEY–MELBOURNE CORRIDOR (INTENSITY LEVEL 1): FREIGHT AFFECTED

(Mt)

Origin–destination pair	*Sydney–Melbourne*
Sydney–Melbourne	1 421
Melbourne–Brisbane	
Adelaide–Sydney	
Adelaide–Brisbane	
Sydney–Perth	
Brisbane–Perth	
Total tonnages on upgraded lines	1 421
Link tonnage	3 113
Percentage of link tonnages on upgraded lines	45.6

Sources ABS 1992d; BTCE estimates.

TABLE XII.5 UPGRADING THE SYDNEY–MELBOURNE AND SYDNEY–BRISBANE CORRIDORS (INTENSITY LEVEL 2): FREIGHT AFFECTED

(Mt)

Origin–destination pair	*Sydney–Melbourne*	*Sydney–Brisbane*
Sydney–Melbourne	1 421	
Sydney–Brisbane		1 520
Melbourne–Brisbane	557	557
Adelaide–Sydney		
Adelaide–Brisbane		
Sydney–Perth		
Brisbane–Perth		
Total tonnages on upgraded lines	1 978	2 077
Link tonnage	3 113	2 296
Percentage of link tonnages on upgraded lines	63.5	90.5

Sources ABS 1992d; BTCE estimates.

TABLE XII.6 UPGRADING THE SYDNEY–MELBOURNE, SYDNEY–BRISBANE AND ADELAIDE–MELBOURNE CORRIDORS (INTENSITY LEVEL 3): FREIGHT AFFECTED

(Mt)

Origin–destination pair	*Sydney–Melbourne*	*Sydney–Brisbane*	*Adelaide–Melbourne*
Sydney–Melbourne	1 421		
Sydney–Brisbane		1 520	
Melbourne–Brisbane	557	557	
Adelaide–Sydney	395		395
Adelaide–Brisbane	147	147	147
Adelaide–Melbourne			1 190
Sydney–Perth			
Melbourne–Perth			
Brisbane–Perth			
Total tonnages on upgraded lines	2 520	2 224	1 732
Link tonnage	3 113	2 296	2 897
Percentage of link tonnages on upgraded lines	81.0	96.9	59.8

Sources ABS 1992d; BTCE estimates.

As successive links are upgraded, the percentage of Sydney–Melbourne link tonnages travelling on upgraded lines rises. With the completion of the Adelaide–Perth line, it is assumed that 100 per cent of the NTPT after-investment tonnage increases are achievable on each link.

FUEL CONSUMPTION AND EMISSION CHANGES

Fuel consumption was calculated as:

$$\underset{\text{(MJ)}}{\text{Fuel consumption}} = \underset{\text{(MJ / tonne-km)}}{\text{Fuel efficiency}} \times \underset{\text{(tonne-km)}}{\text{Tonne-km carried}} \qquad (2.0)$$

Because shifting freight from road to rail is not likely to increase the rate at which newer, more fuel-efficient technologies are introduced, the fuel efficiencies of both road and rail after upgrading of the rail lines were assumed to be equal to the fuel efficiencies before. The change in fuel consumption was calculated as:

$$\Delta\text{Fuel consumption}_i = \text{Fuel efficiency}_i \times \Delta\text{Tonne-km carried}_i \qquad (2.1)$$

where *i* is the mode of transport (road or rail), and Δ represents 'change in'.

To estimate changes in tonne-kilometres, an average distance was calculated by weighting the distance by the proportion of the change in freight travelling along that distance. The average distance represents the average distance over which the change in tonnages travel:

$$\text{Weighted average distance} = \sum \left(\frac{\text{OD tonnes}}{\text{Total tonnes}} \times \text{Distance} \right) \qquad (2.2)$$

where OD tonnes is the number of tonnes carried between an origin–destination pair affected by an upgrade, total tonnes is the sum of the tonnes carried on all origin–destination pairs affected by an upgrade and distance is the distance along each origin–destination pair. The summation is over all OD pairs affected by an upgrade.

When only the Sydney–Melbourne corridor is upgraded, only Sydney–Melbourne origin–destination traffic is affected. The average distance travelled by the freight is therefore equal to the distance between Sydney and Melbourne. This is equivalent to 960 km for rail and 889 km for road.

The upgrading of both the Sydney–Melbourne and Sydney–Brisbane lines will cause changes in the tonnages carried along the Sydney–Melbourne, Sydney–Brisbane and Melbourne–Brisbane origin–destination pairs. Using ABS (1992d) data on the tonnage along each corridor, it was calculated that 40.6 per cent of the change in tonnage will occur along from Sydney–Melbourne freight, 43.5 per cent from Sydney–Brisbane freight and 15.9 per cent from Melbourne–Brisbane freight. This corresponds to an average distance of 1119 km for rail and 1051 km for road (table XII.7).

Applying the same method to successive corridor upgradings yields the average distances shown in tables XII.8 and XII.9.

All corridor traffic was assumed to grow at the same rate. As a result, the weights, and hence the average distances that link freight is carried, will remain constant from 1995–96 to 2014–15. Given that the average distance carried remains constant, the change in tonne-kilometres is calculated using equation (2.3).

$$\Delta\text{Tonne-km}_i = \Delta\text{Tonnes}_i \times \text{Average distance}_i \qquad (2.3)$$

TABLE XII.7 UPGRADING THE SYDNEY–MELBOURNE AND SYDNEY–BRISBANE CORRIDORS (INTENSITY LEVEL 2): AVERAGE DISTANCE FOR FREIGHT AFFECTED

Origin–destination pair	Tonnes carried (Mt)	Proportion[a]	Distance (km)		Proportion × distance (km)	
			Rail	Road	Rail	Road
Sydney–Melbourne	1 421	0.406	960	889	390	361
Sydney–Brisbane	1 520	0.435	970	1013	422	441
Melbourne–Brisbane	557	0.159	1 930	1570	307	249
Total tonnes	3 498					
Average distances					1 119	1 051

a. The proportion is the tonnes carried on an OD link divided by the total tonnes carried (e.g 0.406 = 1421 / 3498).

Sources ABS 1992d; BTCE 1995a, p. 21; BTCE estimates.

TABLE XII.8 UPGRADING THE SYDNEY–MELBOURNE, SYDNEY–BRISBANE AND ADELAIDE–MELBOURNE CORRIDORS (INTENSITY LEVEL 3): AVERAGE DISTANCE FOR FREIGHT AFFECTED

Origin–destination pair	Tonnes carried (Mt)	Proportion[a]	Distance (km)		Proportion × distance (km)	
			Rail	Road	Rail	Road
Sydney–Melbourne	1 421	0.272	960	889	261	242
Sydney–Brisbane	1 520	0.291	970	1 013	282	294
Melbourne–Brisbane	557	0.107	1 930	1 570	206	167
Adelaide–Sydney	395	0.076	1 756	1 447	133	109
Adelaide–Melbourne	1 190	0.228	796	747	181	170
Adelaide–Brisbane	147	0.028	2 726	1 985	77	56
Total tonnes	5 230					
Average distance					1 139	1 038

a. The proportion is the tonnes carried on an OD link divided by the total tonnes carried.

Sources ABS 1992d; BTCE 1995a, pp. 21–22; BTCE estimates.

TABLE XII.9 UPGRADING THE SYDNEY–MELBOURNE, SYDNEY–BRISBANE, ADELAIDE–MELBOURNE AND ADELAIDE–PERTH CORRIDORS (INTENSITY LEVEL 4): AVERAGE DISTANCE FOR FREIGHT AFFECTED

Origin–destination pair	Tonnes carried (Mt)	Proportion[a]	Distance (km)		Proportion × distance (km)	
			Rail	Road	Rail	Road
Sydney–Melbourne	1 421	0.202	960	889	194	180
Sydney–Brisbane	1 520	0.216	970	1 013	210	219
Melbourne–Brisbane	557	0.079	1 930	1 570	153	125
Adelaide–Sydney	395	0.056	1 756	1 447	99	81
Adelaide–Melbourne	1 190	0.169	796	747	135	127
Adelaide–Brisbane	147	0.021	2 726	1 985	57	42
Sydney–Perth	521	0.074	4 383	3 962	325	294
Melbourne–Perth	572	0.081	3 423	3 467	279	282
Adelaide–Perth	626	0.089	2 627	2 720	234	243
Brisbane–Perth	72	0.010	5 353	4 274	55	44
Total tonnes	7 021					
Average distance					1 741	1 636

a. The proportion is the tonnes carried on an OD link divided by the total tonnes carried.

Sources ABS 1992d; BTCE 1995a, pp. 21–22; BTCE estimates.

where *i* represents the mode of transport (road or rail).

The change in tonne-kilometres found in equation (2.3) and the fuel efficiency series were substituted into equation (2.0) to determine the changes in fuel consumed by road and rail.

The fuel efficiency of road freight transport

BTCE (1995c, pp. 215, 217) presents time series for total fuel consumption and total tonne-kilometres travelled for articulated trucks. Dividing the total fuel consumption by total tonne-kilometres yields an average fuel efficiency series (in PJ / tonne-km) for articulated trucks.

Fuel consumption and total tonne-kilometres data were available for LCVs and rigid trucks, but were not incorporated into the fuel efficiency series because these vehicles tend to carry fast freight and it is unlikely that rail would compete in the fast freight market.

Change in road transport emissions

To determine the change in road emissions, the change in fuel consumption was apportioned amongst the various fuels. Trucks use three types of fuel, petrol, automotive diesel oil (ADO) and liquefied petroleum gas (LPG). It was assumed that 99 per cent of fuel used was ADO (BTCE 1995c, p. 215). The remaining 1 per cent was split equally between petrol and LPG, based on 1991 figures for fuel consumption by articulated trucks (Apelbaum 1993, p. 77).

CO_2 emissions were found by multiplying the change in fuel consumption by the emission factors given in **appendix IV**. Because non- CO_2 emission factors for trucks are expressed in g/km, the non-CO_2 emissions were calculated by multiplying the change in total kilometres travelled by the emission factors.

The total change in kilometres travelled was estimated by dividing the total change in tonne-kilometres by the average load. Projections of the average load carried by articulated trucks were taken from BTCE (1995c, p. 215).

CO_2 equivalent emissions were determined by multiplying the emissions of each gas by the relevant global warming potential given in appendix IV.

The fuel efficiency of rail freight transport

Fuel efficiency estimates for government non-bulk trains in BTCE (1995c, p. 227) were used for rail fuel efficiencies. Estimates are also available for the fuel efficiencies of urban passenger, non-urban passenger, government bulk freight and private freight trains. However, these were not incorporated into the fuel efficiency series as intercapital freight is unlikely to shift to these types of trains.

Change in rail emissions

Interstate trains use two types of fuel, automotive diesel fuel (ADO) and industrial diesel fuel (IDF). It is estimated that IDF consumption by interstate freight trains in 1994–95 was 0.87 PJ (BTCE 1995c, pp. 225, 227, 229). Between 1994–95 and 2014–15, IDF consumption was assumed to remain constant (BTCE 1995c, p. 57). The balance of the change in fuel consumption was thus assumed to be ADO.

Changes in rail emissions were calculated in the same way as the change in CO_2 emissions from trucks using the emission factors and global warming potentials given in appendix IV.

APPENDIX XIII VALUE OF TRAVEL TIME AND COSTS OF URBAN TRAFFIC CONGESTION

This appendix refers to the costs of urban congestion estimated specifically for six Australian capital cities using the TRANSTEP model as outlined in BTCE (1996d). The results were used only for abatement measures that were limited to metropolitan areas (such as decreased public transport fares, or increased parking charges) as an adjunct to the ITS/BTCE model (appendix VI). Abatement measures that were analysed using the BTCE CARMOD model (appendix VII) utilised congestion costs already incorporated in a simplified way in CARMOD. Congestion costs estimated from TRANSTEP and CARMOD were consistent in magnitude.

Estimating the costs of urban congestion

Traffic congestion is largely an urban phenomenon. It is a classic example of an economic externality.

Road users considering whether to join a congested traffic stream would normally take account of the travel time plus the vehicle operating costs that they would expect to incur. The sum of these are the (generalised) private costs against which they would weigh the benefits and, beyond a certain point, decide not to travel. But road users do not take account of the fact that their own travel increases congestion and imposes additional costs on others. The economics of congestion are outlined in BTCE (1996d, ch. 4).

To determine the external costs that motor-vehicle travel imposes in terms of congestion is not straightforward. Not only the total costs, but the proportions of those costs that are external, vary with the level of congestion on particular parts of an urban road network. And substantial changes in the level of overall traffic feed back into effects on destination and route choice, as well as altering the patterns of congestion in ways that depend on the idiosyncrasies of particular city layouts.

External costs of congestion on a particular road link are likely to be markedly non-linear with respect to the amount of travel. The total external costs of congestion on a network of road links will therefore depend on how uniformly congestion is distributed. In general, an aggregated analysis that does not consider congestion separately on each road link is unlikely to provide a credible estimate of the costs of congestion.

Using a commercially available model (TRANSTEP), the BTCE modelled traffic flow in six Australian capital cities in some detail, estimated the external cost of congestion on a road-by-road basis, and summed the results to obtain an external cost of congestion. BTCE (1996d) presented estimates of the potential costs and benefits of reducing congestion in Melbourne, Sydney, Adelaide, Brisbane, and Perth. BTCE (1996d) quantified for the first time the errors inherent in modelling urban congestion charges on the aggregated basis used by many researchers, compared with the more detailed network modelling approach employed by the BTCE. It also estimated economically efficient road-user charges for each road link in each of the six capital cities. Due largely to lack of data on urban freight transport, the BTCE analysis of road-user charges was limited to cars, although the TRANSTEP model assumed for each city a given level of ‘background’ freight traffic.

Many of the greenhouse abatement measures analysed in this Report generate changes in traffic levels, particularly in urban areas. Given the capacity (measured as lane-kilometres) of a road network, changes in traffic volume (vehicle-kilometres travelled) will result in changes in congestion. Reductions in congestion have positive social welfare effects (negative costs) that need to be incorporated in any assessment of the costs of implementing a greenhouse gas abatement measure. Similarly, account needs to be taken of the additional social costs of any increase in congestion.

The calibrated models of peak-hour traffic flow described in BTCE (1996d) were altered so as to raise or lower the demand for travel in a uniform fashion, leaving the relativities between long and short trips, and accessible and inaccessible destinations, the same. In crude terms, the ‘demand curves’ for travel were shifted in proportion, raising or lowering the demand for travel without affecting the elasticities of demand. Runs of the several models produced predictions of the travel pattern that might result from levels of traffic between about 30 per cent below and 30 per cent above current peak-hour levels. These were used to calculate the external component of congestion delay, which varied from 83 per cent of congestion costs in the case of the current Adelaide peak hour, to 86 per cent in the case of the current Melbourne peak hour.

The modelling results yielded congestion costs in vehicle-hours per vehicle-kilometre travelled. These were multiplied by the average number of passengers per vehicle in the various cities (a number ranging from 1.2 for Canberra traffic to 1.34 for Melbourne traffic) and by the value of commuting time in the various cities (table XIII.1, fuel cost basis). The results, expressed as an external cost of travel per vehicle-kilometre, are summarised in table XIII.2, where the traffic level is expressed as percentage change from current (1995–96) peak-hour values, and the costs are given in dollars per vehicle-kilometre. Figure XIII.1 shows congestion cost curves for each city. The wide variations between cities are a result of differing current levels of congestion and widely different values of travel time. The peculiar traffic levels in the table result from the idiosyncratic responses of traffic volume in the various cities.

Because average commuting conditions include the peak-hour level of traffic, as well as travel that takes place at lower levels of traffic, an average traffic level was calculated for each city, weighted by the proportion of travel that takes place at the various times. Using these

TABLE XIII.1 VALUE OF URBAN COMMUTER TRAVEL TIME BY CITY

(1995–96 $ per person-hour)

City	*Toll costs basis*	*Fuel costs basis*
Canberra	5.18	6.70
Sydney	44.56	17.12
Melbourne	15.87	10.55
Brisbane	12.09	23.38
Adelaide	22.16	22.76
Perth	108.56	8.91

Note Value of travel time is derived from utility equations as the ratio of the marginal utility of travel time to toll costs; and as the marginal utility of travel time to the marginal utility of fuel costs.

Source Survey conducted by the Institute of Transport Studies, Graduate School of Business, The University of Sydney, under contract to the BTCE.

TABLE XIII.2 EXTERNAL COST OF CONGESTION AS A FUNCTION OF VARIATIONS FROM THE 1995–96 GROSS VOLUME–CAPACITY RATIO IN AUSTRALIAN CAPITAL CITIES

(1995–96 $ per vehicle-kilometre)

Volume–capacity ratio % change	*Adelaide*	*Brisbane*	*Canberra*	*Melbourne*	*Perth*	*Sydney*
–38					0.012	
–37					0.013	
–36					0.013	
–35					0.014	
–34				0.032	0.015	
–33				0.034	0.015	
–32		0.103	0.006	0.035	0.016	
–31		0.107	0.006	0.037	0.016	
–30	0.034	0.111	0.007	0.039	0.017	0.189
–29	0.035	0.114	0.007	0.040	0.018	0.190
–28	0.037	0.118	0.007	0.042	0.018	0.190
–27	0.038	0.122	0.007	0.044	0.019	0.191
–26	0.040	0.126	0.008	0.045	0.020	0.192
–25	0.041	0.129	0.008	0.047	0.021	0.192
–24	0.042	0.133	0.008	0.049	0.022	0.193
–23	0.044	0.137	0.008	0.051	0.023	0.194
–22	0.045	0.140	0.009	0.053	0.024	0.195
–21	0.047	0.143	0.009	0.055	0.024	0.195
–20	0.048	0.146	0.009	0.057	0.025	0.196
–19	0.050	0.149	0.010	0.058	0.026	0.197
–18	0.052	0.152	0.010	0.060	0.027	0.197
–17	0.054	0.155	0.011	0.062	0.028	0.198
–16	0.056	0.158	0.011	0.064	0.029	0.199
–15	0.058	0.161	0.012	0.066	0.030	0.199
–14	0.059	0.164	0.013	0.069	0.031	0.200
–13	0.061	0.168	0.013	0.071	0.032	0.201
–12	0.063	0.173	0.014	0.074	0.033	0.201
–11	0.065	0.177	0.014	0.077	0.034	0.202
–10	0.067	0.181	0.015	0.080	0.035	0.202
–9	0.069	0.185	0.016	0.082	0.036	0.203
–8	0.071	0.190	0.016	0.085	0.037	0.204
–7	0.073	0.194	0.017	0.085	0.039	0.204
–6	0.075	0.197	0.018	0.088	0.040	0.205
–5	0.077	0.200	0.019	0.090	0.042	0.206
–4	0.078	0.203	0.019	0.093	0.043	0.206
–3	0.080	0.205	0.020	0.095	0.045	0.207
–2	0.082	0.208	0.021	0.098	0.046	0.207

Continued on next page

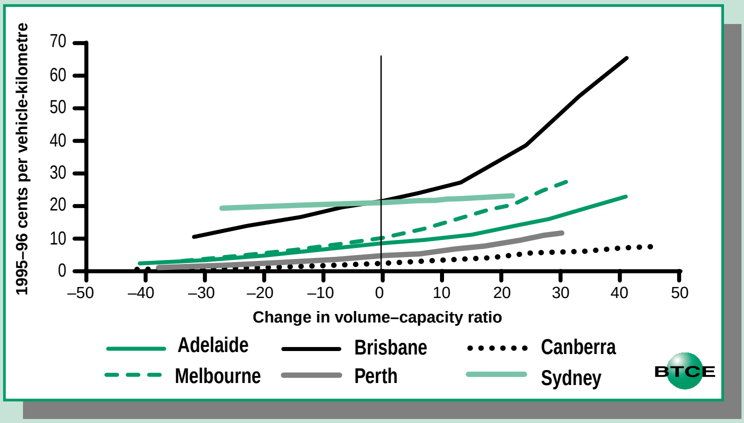
TABLE XIII.2 EXTERNAL COST OF CONGESTION AS A FUNCTION OF VARIATIONS FROM THE 1995–96 GROSS VOLUME–CAPACITY RATIO IN AUSTRALIAN CAPITAL CITIES (continued)

(1995–96 $ per vehicle-kilometre)

Volume–capacity ratio % change	*Adelaide*	*Brisbane*	*Canberra*	*Melbourne*	*Perth*	*Sydney*
–1	0.084	0.211	0.021	0.100	0.048	0.208
0	0.086	0.214	0.022	0.103	0.049	0.208
1	0.087	0.218	0.023	0.107	0.050	0.209
2	0.089	0.222	0.024	0.111	0.051	0.210
3	0.090	0.226	0.025	0.115	0.052	0.211
4	0.092	0.230	0.026	0.119	0.052	0.212
5	0.093	0.234	0.027	0.123	0.053	0.213
6	0.095	0.238	0.028	0.127	0.054	0.214
7	0.096	0.243	0.029	0.131	0.057	0.214
8	0.098	0.249	0.030	0.136	0.059	0.215
9	0.100	0.254	0.031	0.142	0.062	0.215
10	0.102	0.259	0.032	0.147	0.064	0.217
11	0.104	0.265	0.033	0.152	0.067	0.219
12	0.106	0.270	0.034	0.158	0.069	0.220
13	0.108	0.279	0.035	0.163	0.071	0.220
14	0.110	0.288	0.035	0.168	0.073	0.221
15	0.112	0.297	0.036	0.174	0.074	0.222
16	0.116	0.305	0.037	0.179	0.076	0.223
17	0.120	0.314	0.038	0.185	0.078	0.224
18	0.123	0.323	0.039	0.190	0.081	0.225
19	0.127	0.332	0.041	0.194	0.084	0.226
20	0.131	0.342	0.043	0.198	0.087	0.227
21	0.135	0.353	0.045	0.201	0.090	0.228
22	0.138	0.363	0.048	0.205	0.093	0.229
23	0.142	0.374	0.050	0.214	0.096	0.230
24	0.146	0.384	0.052	0.222	0.100	0.231
25	0.149	0.401	0.054	0.231	0.104	0.232
26	0.153	0.418	0.055	0.239	0.107	0.233
27	0.156	0.434	0.055	0.248	0.111	0.234
28	0.160	0.451	0.056	0.253	0.113	0.235
29	0.165	0.468	0.056	0.259	0.118	0.236
30	0.171	0.485	0.057	0.264	0.118	0.237
31	0.176	0.501	0.057	0.270		
32	0.181	0.518	0.058	0.275		
33	0.187	0.535	0.058			
34	0.192		0.059			

Source BTCE application of TRANSTEP model.

FIGURE XIII.1 EXTERNAL COST OF CONGESTION AS A FUNCTION OF TRAFFIC LEVEL IN AUSTRALIAN CAPITAL CITIES



Source BTCE modelling results.

average traffic levels and the dependence of congestion costs on traffic levels given in table XIII.2, a deflator for average congestion costs was calculated for each city. The values of these deflators were 0.5 for Adelaide, Canberra and Perth and 0.6 for Brisbane and Melbourne. Because the average external costs of congestion for Sydney vary little with the volume of traffic over the relevant range, the deflator for Sydney is 0.9.

Modelling of congestion in BTCE (1996d) was based on existing levels of traffic in existing cities. However, the measures analysed in this Report are based on the future, specifically the period 1996 to 2015.

A city's population increases over time, and this growth **(table I.5)** is reflected in an increase in urban traffic (derived from tables I.5 and **II.5**). If the capacity of the road network did not increase, congestion would be a lot worse each year. But new roads will be built in new suburbs, existing roads will be widened and upgraded, and new projects will be undertaken in areas that are already developed, to accommodate rising demand for travel. It is not possible to account accurately for the effects of these programs without detailed modelling of projected changes in road networks. Such a task would have been beyond the scope of this Report, so changes in urban road networks were approximated by adjustments to the gross volume–capacity ratio of each city.

A major assumption made was that the road capacity in each city would grow proportionately with the projected increase in motor vehicle traffic (vehicle-kilometres travelled—VKT) in that city. A second assumption was that, in each year, approximately half of the increase in traffic would travel on new road capacity, and that the remainder would travel on capacity existing in the previous year, resulting in an increase in the volume–capacity ratio. The result of these assumptions is that the effective capacity of the road system in each city is expected to grow at only half the rate of vehicle travel.

The effective capacity of the road network in each city, in any year after the base year 1996, will thus equal the capacity in 1996 multiplied by the square root of the ratio of the projected volume of traffic (VKT) in the future year to the volume of traffic in 1996. That is:

$$\text{Effective capacity in year X} = \text{Effective capacity in 1996} \times \sqrt{\frac{\text{VKT in year X}}{\text{VKT in 1996}}}$$

The growth rate in effective capacity is then given by:

$$\text{Percentage growth in effective capacity in year X} = 100\% \times \left(\sqrt{\frac{\text{VKT in year X}}{\text{VKT in 1996}}} - 1\right)$$

It is possible to estimate the external cost of congestion in any scenario as follows:

1. Estimate the level of traffic in each city in the scenario, in the relevant year.
2. Divide the scenario level of traffic in each city by the 1996 level of traffic in the scenario in each city.
3. Divide these quotients by the effective network capacity forecast for the corresponding cities in the appropriate year, setting effective capacity in 1996 equal to 1.
4. Express the results as percentage changes from the current volume–capacity ratios for each city (i.e., subtract 1 from results and multiply by 100).
5. Find the corresponding external costs per vehicle-kilometre from table XIII.2.
6. Multiply these costs by the corresponding numbers of vehicle-kilometres, to obtain costs in each city.
7. Sum the results over the several cities to obtain a total cost.

For example, 26 355 849 229 vehicle-kilometres are travelled in Melbourne in 1995–96. VKT is projected to be 27 959 676 071 in the year 2000. Dividing them gives about 1.06, a 6 per cent increase. Using the formula above, effective capacity is projected to increase by a factor of 1.03. From these two numbers, the increase in the volume–capacity ratio is calculated to be about 3 per cent. Table XIII.2 shows that with a 3 per cent increase in the volume–capacity ratio, the external costs of congestion are \$0.115 per VKT. The total external cost of congestion in Melbourne in the year 2000 under this scenario is therefore: \$0.115/VKT × 27 960 million VKT = \$3215 million.

This method allows an estimate of the effects on the external costs of traffic congestion of any instrument that influences demand for urban car travel, so long as the changes in volume–capacity ratios in each city remain within the bounds of the figures presented in table XIII.2.

The value of time spent travelling

The cost of travel is generally measured as the total, 'generalised' cost of a trip (journey). Generalised cost includes not only financial outlays for items such as train fares or for petrol and other vehicle operating costs, but also the value of time spent making the trip.

In practice, the key determinant of the generalised cost of travel is the value assigned to time spent travelling (travel time). BTCE (1996a, appendix V) provides a brief overview of different Australian estimates of travel time. The value of travel time used throughout this Report is derived from the ratio of the marginal utility of travel time to the marginal utility of fuel costs for the urban commuter households represented in the ITS/BTCE model. No separate estimates were made or used for travel time values for commercial vehicles.

An overall national (fuel based) value of commuter travel time of \$15.19 was obtained from table XIII.1 by averaging the value of time for each city weighted by its expected population in 1995–96 (table I.5). It is important to note that BTCE (1996d) used an average value of travel time for all six capital cities of \$9 per hour.

Table XIII.1 presents values of travel time for urban commuters both on the basis of fuel costs, and on the basis of an alternative estimate based on road tolls. It is arguable that the estimate of travel time on the basis of road tolls is conceptually superior, because tolls represent a direct trade-off against travel time. The value based on tolls was not used by the

BTCE because it was not clear that households in cities such as Melbourne had had sufficient experience of tolls to provide an informed response (in stated preference surveys) when presented with the choice of faster travel on a tollway and slower, but free travel on other roads.

Considerable caution needs to be exercised in using the results of any evaluation of the costs of congestion. Costs are based on aggregations of delays for a range of commuter trips. Some delays are substantial in terms of time lost, but some are relatively short. All of these delays (measured in units such as minutes) are multiplied by the same travel value of time to produce a value of time lost due to delay. Because of the large number of commuters involved, even short delays may result in a large aggregated cost.

However, short delays may not have the same cost as longer ones. Small losses in time may be capable of being made up relatively easily by changing priorities or in some other way. Large losses in time may well have a higher opportunity cost because desirable, alternative activities are forgone entirely. Similarly, a small gain in time may not be able to be used productively, whereas a large saving in time can be used in a valuable way. BTE (1982b, ch. 4) explores some of the issues.

It is therefore recommended that any results regarding changes in costs of congestion be assessed against the background of the significant degree of uncertainty attached to the valuation of travel time.

GLOSSARY

Adaptation An alternative to policies to reduce emissions of greenhouse gases is the implementation of measures to adapt to climate change itself. Examples of adaptation measures include building sea walls or relocating activities away from the coast, higher bridges over rivers, better insulation of buildings, or genetic engineering of crops to permit growth under changed climatic conditions.

Adiabatic Compression or expansion of a gas without heat flow to the surrounding material.

Aerosols Small particles and very small droplets of natural and human origin that occur in the atmosphere, often due to dust storms, volcanic eruptions, sulphur-containing industrial emissions, and soot from burning biomass and fossil fuels.

Airframe Aircraft body and wings.

Annual average daily traffic (AADT) The total number of vehicles passing a given point during a specified year, divided by the number of days in a year.

Anthropogenic (or enhanced) greenhouse effect Radiative forcing due to increased concentrations of some greenhouse gases in the atmosphere as a result of human activity. Anthropogenic activity can also generate atmospheric emissions such as aerosols or dust which may reduce the effect of greenhouse emissions.

Articulated trucks Road freight vehicles consisting of a prime mover (having no significant load carrying area), but linked to a trailer with a turntable device.

Automotive diesel oil (ADO) A medium petroleum oil (obtained from the distillation of crude oil) used as fuel in high and medium speed compression ignition engines (other than aviation piston engines). It is mainly used in heavy road vehicles, rail transport, agricultural equipment and mining equipment.

Automotive gasoline *See* **petrol**

Average aircraft availability Average number of a particular type or model of aircraft in the fleet over a year. For example, if there were twenty B737s in a fleet for the first half of the year and eighteen for the remainder of the year, the average number of B737s in the fleet over the year would be 19 (19 aircraft = $20 \times \frac{1}{2} + 18 \times \frac{1}{2}$).

Average aircraft utilisation Represents the average hours flown by one aircraft over one full year and is calculated by dividing hours flown by average aircraft availability. Total hours flown is the aggregate of all flying time and covers hours flown on scheduled, non-scheduled and non-revenue operations. All flying times are calculated on a chock-to-chock basis and therefore include taxiing time.

Aviation gasoline (avgas) A light petroleum oil used in aviation piston engines, mainly in the general aviation sector.

Aviation turbine fuel (avtur) A medium petroleum oil used as fuel for aviation turbine (jet) engines.

AVMOD BTCE spreadsheet model of the scheduled domestic aviation fleet composition and aircraft utilisation. The spreadsheet allows simulation of future domestic aviation emissions under differing assumptions about the timing of retirement of aircraft and the type of aircraft entering the fleet, in order to forecast the future composition of the aircraft fleet. **(See appendix IX).**

Basecase In order to evaluate the effectiveness of abatement measures over some future period, it is necessary to establish a basecase (or 'business as usual' scenario) of greenhouse gas emissions. A basecase is usually estimated on the basis of econometric projections on the assumption that no specific action is taken to reduce greenhouse emissions. Econometric projections by transport mode are presented in BTCE (1995c), and annual projected basecase levels of greenhouse emissions for the period 1996 to 2015 are given in **appendix III**.

Black coal In this Report, black coal refers to steaming coal used in the transport sector, primarily for shipping.

Block speed *See* **mean block speed**.

Brake thermal efficiency Ratio of work done by the engine in propelling the vehicle forward to the amount of energy contained in the fuel.

Bunker A storage facility for shipping and aviation fuel. The term 'bunkers' normally refers to fuel taken on by international shipping or aircraft.

Buses *See* **mobile sources—road transport**.

CAFE (corporate average fuel economy) In response to the energy crises of the 1970s, the US Congress passed the Energy Policy and Conservation Act of 1975 (PL 94-163), which required vehicle manufacturers to meet fuel economy targets, beginning at 18 miles per gallon (MPG) in 1978 and increasing to 27.5 MPG by 1985. Efficiency targets were also specified for light trucks. Compliance is measured by the corporate average fuel economy (CAFE) number, which is the sales-weighted harmonic mean MPG of a manufacturer's products. The targets must be met for domestic and imported fleets.

Cam Revolving lobe, usually of eccentric shape, fixed on a shaft and able to convert rotary motion to reciprocating or oscillating motion for a component in contact with the cam. Cams are employed to operate the valves of four-stroke engines.

Carbon canisters Devices (usually containing activated charcoal) attached to fuel systems vents of vehicles to absorb evaporative emissions of volatile organic compounds.

Carbon dioxide (CO_2) equivalent The concentration of CO_2 necessary to have the same amount of radiative forcing as the mass of the greenhouse gas concerned (appendix IV). CO_2 equivalents are calculated by multiplying the weight of the greenhouse gas by its global warming potential.

Carbon leakage *See* **emissions leakage.**

Carbon sink A mechanism that sequesters carbon extracted from the atmosphere. Natural carbon sinks include trees (and other vegetation) which photosynthesise CO_2 into wood, and marine organisms that secrete CO_2 as calcium carbonate ($CaCO_3$) in forms such as oyster shells. Carbon sinks can also be created by pumping atmospheric CO_2 under the oceans or into terrestrial cavities such as oil wells.

Carbon tax A tax on the carbon content of primary fossil fuels.

CARMOD A spreadsheet model of the Australian car fleet developed by the BTCE to simulate how fleet characteristics such as average vehicle age, total annual distance travelled, average fuel consumption and total emissions change over time. The model incorporates vehicle age-specific factors for scrapping rates, fuel consumption, annual kilometres travelled, and emission rates. **(See appendix VII.)**

Car pooling Sharing of private vehicles on a regular basis, usually for commuting to and from work.

Cars *See* **mobile sources—road transport**.

Catalyst Substance that alters the velocity of a chemical reaction and may be recovered essentially unaltered in form and amount at the end of the reaction.

Catalytic converter An emission control device fitted in the exhaust system of spark ignition engines to reduce the pollutant potential of combustion products (exhaust gases). Three-way catalytic converters (so called because they deal with three pollutant types using three distinct chemical pathways) used in petrol driven cars contain catalysts that promote the conversion of CO, hydrocarbons, and NO_x into CO_2, water (H_2O) and nitrogen (N_2), thereby reducing noxious exhaust emissions into less reactive substances. Because the catalysts used are deactivated by lead, cars with these converter systems must be run on unleaded petrol. Catalysts used in catalytic converters include rhodium.

Ceramics Composite non-organic, non-metallic materials that are brittle, low in weight and highly resistant to chemical action. They have great surface hardness, with good frictional and wear properties, low thermal conductivity but low resistance to thermal shock. Car manufacturers employ ceramic materials for some engine components to improve the frictional properties or reduce the heat loss through low thermal conductivity.

Chapter 2/Chapter 3 Refers to the agreed regulations laid down by the International Civil Aviation Organisation (ICAO) to restrict the amount of noise pollution produced by aircraft. Chapter 2 noise pollution standards for jet aircraft were introduced in the early 1970s, while Chapter 3 noise pollution standards were introduced in 1977. Chapter 2/Chapter 3 is the International Civil Aviation Organisation reference to noise pollution standards, and stage 2/stage 3 is the US terminology.

Clearances The horizontal and vertical clearances which determine the size of loads that can be taken through a rail corridor.

Climate change (FCCC usage) A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. *See also* **Climate change (IPCC usage), Framework Convention on Climate Change.**

Climate change (IPCC usage) Climate change as referred to in the observational record of climate occurs because of internal changes within the climate system or in the interaction between its components, or because of changes in external forcing either for natural reasons or because of human activities. It is generally not possible clearly to make attribution between those causes. Projections of future climate change reported by IPCC generally consider only the influence on climate of anthropogenic increases in greenhouse gases and other human-related factors. *See also* **Climate change (FCCC usage), IPCC.**

Close coupling An automotive engineering practice where the catalytic converter is positioned close to the exhaust manifold, using the heat generated by the engine to reduce the time taken for the catalyst to attain its operating temperature.

Clunkers Defined in this Report as cars older than 12 years, and assumed to have higher rates of non-CO_2 emissions and higher fuel usage than the average vehicle of equal age. The term 'clunker' is of North American usage.

Consumer surplus The difference between the amount that a consumer is willing to pay for a good or service (rather than go without it), and the amount actually paid. *See also* **economic cost, producer surplus.**

Conversion rate *See* **emission factors.**

Cycle tests Carried out on a chassis dynamometer, cycle tests simulate different driving conditions to measure fuel consumption and emissions on a standardised basis.

Diesel fuel Diesel is normally produced by blending two or more refinery streams such as light and heavy gas oil, and comprises a mixture of paraffinic, aromatic and olefinic hydrocarbons. Because hydrocarbons in diesel contain 12 or more carbon atoms per molecule, it is 'heavier' than petrol and is therefore a less volatile fuel. The net energy value of diesel is 35.6 megajoules per litre. *See also* **petrol.**

Direct greenhouse gas Radiatively active (re-emitting infrared radiation both upwards and downwards) gases such as CO_2, CH_4, N_2O and fluorocarbons. *See also* **greenhouse gases, indirect greenhouse gas.**

Discount rate A discount rate of 10 per cent (real) per annum has been used throughout this Report. Money can be used to finance current consumption, or it can be invested now and the proceeds of the investment can be reinvested or used to finance future consumption. Given the existence of interest rates and the possibility of borrowing and lending, money has a 'time' value. (In other words, individuals have a rate of time preference). Since the value of a sum of money depends on the time that it is received (benefit) or spent (cost), benefits and costs (expressed in money terms) that accrue at different times need to be converted to a common 'present value' to permit valid comparisons between them. The present value of social costs (SC) is given by:

$$\sum_{i=0}^{n} \frac{SC_i}{(1 + r)^n}$$

where r is the discount rate and n is the number of years over which the analysis is carried out.

In cost–benefit analysis, the discount rate needs to reflect the opportunity cost to society as a whole of delaying consumption or the receipt of income or other benefits, and is therefore referred to as the social discount rate. *See also* **externality, social cost, social discount rate.**

Diurnal emissions Evaporative hydrocarbon emissions from the vehicle fuel system resulting from normal daily temperature changes causing the air–fuel mixture in the tank to expand and expel petrol vapour. *See also* **hot soak, running losses.**

Double stacking Loading of one container on top of another on a special railway wagon called a well wagon. Operational efficiencies can be derived from double stacking by enabling twice the number of containers to be carried for the same length of train.

Downsizing Used in this Report to denote decision by motorists to purchase smaller, more fuel-efficient cars.

Economic cost A cost is a measure of what has to be given up in order to achieve or acquire something. Costs are generally expressed in money terms to permit comparison of alternatives in a common numeraire, but could also be expressed in terms of a common non-monetary standard such as a hamburger or a Mars bar.

Costs are most often defined in terms of money outlays or expenditure. In this form, they are usually called financial costs. An example of a financial cost is the amount paid for petrol by a motorist, whose private cost is calculated as the product of the retail price of petrol (cents/litre) and quantity (litres) to give a total expenditure in cents. Financial costs are typically used by accountants, who have traditionally been concerned with recording and presenting money flows that have occurred in the past.

Economists measure costs in terms of the most valuable alternative or opportunity forgone in order to achieve or acquire something. (Because the economic approach is based on opportunity, it looks to the future and may therefore be called an *ex ante* concept to distinguish it from the accountant's *ex post* approach to calculating cost.) For example, the (historical) financial cost of a block of land purchased ten years ago may be recorded by an accountant as an asset value of $1000, the price paid at the time of purchase. However, the opportunity cost (that is, value) of the land would be measured by an economist as the current market value of the block, whether it is higher or lower than the historic cost of $1000. The opportunity cost of the land reflects its value to its owner in alternative uses, including selling it and using the proceeds for consumption or further investment. Opportunity costs can therefore be equal to financial costs if and only if the prices in which expenditure is calculated correctly reflect the value of the resource in alternative uses.

Economic costs reflect opportunity costs. However, even where prices of resources reflect accurately their value in alternative uses (so that financial costs of physical resources used can be considered equal to their opportunity cost), economic costs also need to include any changes in utility or welfare. For example, a government regulation that prohibits cars from the central business district (CBD) will generally result in a loss of consumer (and/or producer) surplus. Loss of consumer surplus represents an opportunity cost to those who would have been willing to pay some generalised travel cost to continue to travel into the CBD. The actual (net) economic cost of the government's ban on cars entering the CBD to each individual would require adjustments for effects such as the financial cost of petrol saved (but possibly offset by the financial costs of public transport if a trip is still made), and the value of any time 'saved' by not making the trip (or additional time used or loss of convenience because public transport is used). Because variables such as consumer surplus and time are not traded in markets, their values cannot be observed directly and can usually only be estimated by using indirect techniques.

Where economic costs need to be calculated on a national level, as in the case of greenhouse abatement measures analysed in this Report, it is necessary to estimate social economic costs in order to reflect the value of alternatives to the community as a whole. Social economic costs can normally be determined by aggregating the (private) economic costs of individuals, and adjusting the total to take account of externalities and other market distortions. Where individual behaviour generates externalities, for example, their value needs to be added in to reflect the (public) cost or benefit to society as a whole. Transfer payments such as taxes (e.g. the fuel excise included in the retail cost of petrol to an individual), are normally netted out. Imposition of a carbon tax, for example, would involve private economic costs such as loss in consumer surplus, but the value of government revenue from the tax (which itself represents some of the consumer surplus lost) would be excluded from a calculation of social economic cost because it is simply a transfer from one part of the community (motorists) to another (all residents). However, the benefits (negative costs) of any reduction in urban congestion or noxious emissions would need to be included as part of the social cost of a carbon tax.

See also **externalities**, **consumer surplus**, **generalised travel cost**, **producer surplus, resources**, **social cost**, **transfer payment, welfare**.

Elasticity A measure of the percentage change in one variable in response to a percentage change in another variable. It is a unit-free measure of the degree to which a dependent variable of a function changes in response to a change in an explanatory variable. The point elasticity of a function, f(x), with respect to x is defined as:

$$\varepsilon_{f,x} = [x/f(x)][df(x)/dx] = d \ln f(x)/d \ln x$$

where ln is natural logarithm.

Emission factors Coefficients specifying standard rates of emission per unit of activity (such as grams per kilometre travelled). Emission factors are generally based on measurement data (such as vehicle emission tests), averaged to provide representative emission rates for a given activity under a given set of operating conditions.

Emission intensity The amount of greenhouse gases produced per unit of fuel burned.

Emissions (carbon) leakage Where a country takes measures to reduce greenhouse emissions in a way that increases costs of production, then its exports (or domestic sales) of the commodity involved may become uncompetitive. If production is transferred to another, lower cost country which has not taken similar abatement measures, there is said to be emissions (or carbon) leakage. Where leakage migrates to a country which is less efficient in emission output, the net result of abatement measures taken in the first (abating) country may be a global increase in emissions.

End-use emissions Refers to emissions resulting solely from vehicle operation. *See also* **cycle tests, evaporative emissions, full fuel cycle emissions.**

ENERGYMOD Based on CARMOD, the BTCE model ENERGYMOD was designed specifically to evaluate the effects of fuel efficiency labelling of new cars. It incorporates assumptions about proportions of new car buyers who switch to more fuel-efficient cars over time, and the costs involved in a labelling scheme.

Equivalent standard axle loading (ESAL) The number of standard 8.5-tonne single-axle loads or dual tyres which would cause the same damage as a single pass of the load and axle configuration in question. *See also* **pavement loading.**

Evaporative emissions Gaseous hydrocarbons can be emitted from the vehicle fuel system in a number of ways. *See also* **diurnal emissions, fugitive emissions, hot soak, running losses.**

Exogenous variable A variable which, although playing an important part in a model, is determined by forces outside the model. For example, travel behaviour in the ITS/BTCE model **(appendix VI)** depends on petrol prices. But the model itself does not try to explain what determines petrol prices. Petrol prices are said to be determined exogenously and are provided merely as inputs to it.

Externality Externalities occur when one individual production or consumption activity imposes costs or benefits on others. In market transactions, these costs and benefits are not normally reflected in the prices involved in the transaction, or taken into account in the transaction decision. The usual example of such a 'market failure' is the smoky factory that affects those around it adversely (a negative externality). Greenhouse emissions are particularly complex to analyse because they have the additional characteristic that they affect everyone on the earth due to the ultimate mixing of atmospheric concentrations. But because climate change is expected to differ by region, not everyone will be affected equally, or even negatively. *See also* **Pigovian tax, social cost.**

Feebate Feebates are lower sales taxes (fees) on more fuel-efficient cars. Buyers of smaller, more fuel-efficient cars pay lower sales taxes, or even receive a cash rebate from the government in the case of particularly fuel-efficient vehicles.

Financial costs Money outlay or expenditure. *See also* **economic cost**.

Fleet Term used to denote the entire Australian (or other specified) population of a particular type of vehicle, including aircraft, cars and trucks and light commercial vehicles.

Fluorocarbons (FCs) Various gases used as refrigerants in vehicle air-conditioners. These include chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs). The main refrigerant used in Australian vehicle air-conditioners is a chlorofluorocarbon denoted by CFC-12. Under the provisions of the Montreal Protocol on Ozone Depleting Substances (which calls for the phasing out of chlorofluorocarbon use) Australian legislation requires that all new vehicle air-conditioning systems manufactured after the end of 1994 will use CFC substitutes. *See also* **fugitive emissions.**

Fossil fuel Fuel derived from once living organisms fossilised by geological forces over extremely long periods of time. Such materials range from natural gas to petroleum, tar sands and oil shales, and from peat through bituminous coal to anthracite. Wood from trees is not a fossil fuel. Hydrogen and ethanol are non-fossil fuels, but fossil fuels may be used in their production. *See also* **primary energy.**

Framework Convention on Climate Change (FCCC) The text of the Convention (sometimes called the Rio Treaty) adopted at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in June 1992. It entered into force on 21 March 1994 following ratification by the requisite 50 countries, including Australia, which ratified it in December 1992.

Fuel efficiency The number of kilometres travelled by a vehicle per litre of fuel (*see also* **fuel intensity**). In aviation, fuel efficiency is typically measured for passenger routes as seat-kilometres per litre of fuel.

Fuel intensity The inverse of fuel efficiency. Refers to the intensity of fuel use, and is typically measured in litres per 100 kilometres for road vehicles.

Fuel oil A heavy petroleum oil, often the residue of petroleum distillation, used in ship furnaces.

Fugitive emissions Gaseous emissions that result from the leakage of chemical substances during various human activities. The main fugitive emissions from mobile sources occur through the evaporation of fuel from petrol powered vehicles (*see* **evaporative emissions**) and the release of fluorocarbons from vehicle air-conditioners.

Full fuel cycle emissions Emissions resulting from end-use plus those resulting from feedstock extraction and refining, power generation, and energy distribution. *See also* **cycle tests, end-use emissions.**

General aviation Includes commuter and charter services, private and training flights and aerial agricultural work.

General equilibrium analysis In contrast to the partial equilibrium analysis adopted in this Report, general equilibrium analysis takes into account interactions between all markets and sectors in an economy. It therefore takes into account the possibility that changes in a sector such as transport may not only induce changes in another sector of the economy, but that the induced changes will in turn affect the transport sector. *See also* **partial equilibrium analysis**.

Generalised travel cost The cost of undertaking a trip is the sum of financial outlays and the value of time spent on the journey. Financial outlays include both those that represent the cost of resources used (such as expenditure on petrol, parking charges, road tolls, or fares for public transport), as well as transfer payments such as excise on petrol. The value of travel time can be estimated from utility equations (appendix V), or a proxy variable such as hourly wage rates can be used. Travel time values used in this Report are given in appendix XIII.

Global warming potential (GWP) An index of the cumulative radiative forcing between the present and some chosen later time horizon caused by a unit mass of greenhouse gas emitted now, and expressed relative to an equal mass of CO_2. GWPs used in this Report are for 100-year time horizons and are detailed in appendix IV.

Greenhouse effect The phenomenon whereby water vapour and other gases present in small quantities in the atmosphere affect the earth's radiation balance, resulting in a higher surface temperature. The greenhouse effect occurs naturally, but can be exacerbated as a result of increased atmospheric concentrations of greenhouse gases resulting from human activity. *See also* **anthropogenic greenhouse effect, greenhouse gases.**

Greenhouse gas emissions Emissions analysed in this Report are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), oxides of nitrogen (NO_x) other than nitrous oxide, carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs). *See also* **greenhouse gases.**

Greenhouse gas emission reductions References in this Report to reductions in greenhouse gas emissions mean a reduction in the emission of CO_2 equivalent gases relative to basecase projections. Unless specifically stated or implied, 'reduction' does not mean a reduction in the absolute level of emissions.

Greenhouse gases Include the direct greenhouse gases carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorocarbon (FC) species, and the indirect greenhouse gases oxides of nitrogen (NO_x) other than nitrous oxide, carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs). Water vapour (H_2O) is the major greenhouse gas but is generally ignored in greenhouse gas inventories because human output is negligible when compared with precipitation. Sulphur oxides (SO_x) affect the atmosphere in ways that are not certain, and are therefore excluded from the analysis in this Report. *See also* **direct greenhouse gas, indirect greenhouse gas.**

Gross calorific value (GCV) The quantity of heat released by a unit quantity of fuel when it is burned completely with oxygen, and the products of combustion are returned to ambient temperature. GCV is also known as higher heating value.

High-bypass turbofan The most widely used form of propulsion for passenger jet aircraft today. The high-bypass turbofan is similar to a turbofan engine but generates greater propulsion by sending five to six times as much air around the core turbine engine.

Hot soak Evaporative emissions of hydrocarbons from the vehicle fuel system that occur at the end of each vehicle trip when engine heat causes evaporation from the carburettor and petrol tank. *See also* **diurnal emissions, evaporative emissions, running losses.**

Hush-kitting A muffling operation that reduces the noise emitted by aircraft engines. Hush-kitting is most frequently used to reduce the amount of noise emitted by older aircraft, so that these aircraft meet noise emission standards.

Hydrocarbon A chemical compound that contains only carbon and hydrogen. It is the principal constituent of liquid fossil fuels.

Hypersonic aircraft Aircraft that can travel through the air at more than five times the speed of sound.

Inclusive value In a discrete-choice model, the expected value of the maximum of the utilities (consumer surpluses) of a group of possible choices. **(See appendix V.)**

Incremental cost In this Report, the additional cost of a finite change in greenhouse emissions. Identical in principle to marginal cost, except that units of change in greenhouse emission reductions are, for practical reasons, larger than the theoretically very small (infinitesimal) values by which marginal analysis is defined. *See also* **marginal cost.**

Indirect greenhouse gas Radiatively inactive (not re-emitting infrared radiation) gases such as CO, NO_x and NMVOCs. These do not themselves have strong radiative effects, but they do influence the concentrations of direct greenhouse gases. *See also* **direct greenhouse gas, greenhouse gases.**

Industrial diesel fuel (IDF) A heavy petroleum oil used as fuel in low speed compression ignition (diesel) engines. It is mainly consumed in the rail and marine transport sectors.

Instrument *See* **measure**.

Intercooler System for reducing the temperature of air entering a turbocharged engine. Cooling is performed by an air-to-air radiator system or by using a watercooled heat exchanger unit between the turbocompressor and inlet manifold system. The lower temperature increases the air density, allowing more mixture to enter the engine, increasing the efficiency and reducing the tendency to knock due to excessive compression temperatures. The main advantages of such a system are that it can increase power output by as much as 20 per cent, and the reduced wear and tear on the engine because the cooler blast mixture helps lower the general temperature of the engine.

Interim Planning Target Based on the Toronto target, and adopted in October 1990 by the Australian Government, the Interim Planning Target forms the basis of the 1992 National Greenhouse Response Strategy. It aims to stabilise greenhouse emissions at 1988 levels by the year 2000 and to reduce them by 20 per cent by 2005, subject to a caveat that Australia should not suffer adverse economic effects in the absence of similar action by major greenhouse producing countries.

IPCC (Intergovernmental Panel on Climate Change) The principal international body investigating greenhouse issues, the IPCC was established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environmental Programme (UNEP).

ITS/BTCE model A behavioural model of urban household demand for travel in six Australian capital cities developed under contract to the BTCE by the Institute of Transport Studies at the University of Sydney **(appendix VI)**.

Joint implementation Provided for under article 4 of the Framework Convention on Climate Change, joint implementation involves cooperation between two countries, with one funding emission reduction in the other to help the first meet its reduction commitments.

Laminar flow Refers to fluid flow in which streamlines are invariant and maintain uniform seperation, with perfect non-turbulent sliding between. Laminar flow control technologies attempt to minimise turbulence and reduce drag.

Life cycle emissions Full fuel cycle emissions plus those resulting from vehicle manufacture and vehicle disposal. Including emissions due to the provision of transport infrastructure results in a systems cycle. *See also* **end-use emissions, full fuel cycle emissions.**

Light commercial vehicle (LCV) *See* **mobile sources—road transport**.

Liquefied petroleum gas (LPG) LPG can be produced from raw natural gas (mostly methane, CH_4) or by refining crude oil. It is a light mixture of hydrocarbons which are gaseous at normal temperatures and pressures, and whose main component gases are propane (C_3H_8), propylene (C_3H_6), and butane (C_4H_{10}).

Linked *See* **trip linking, unlinked**.

Load factor A percentage measure of airline traffic as a proportion of airline capacity. Passenger load factor is the number of passengers carried as a percentage of the number of seats available. Weight load factor is the number of tonne-kilometres performed as a percentage of tonne-kilometres available. Load factor may be measured for a single flight, an airline, or industry wide.

Logistic curve A graph of the logistic function $g(t) = K/(1+ae^{-bt})^{-1}$ with K, a and b constants. Its value increases with time (t) and it has an upper asymptote of K. The logistic curve is typically used to model market penetration of a new product or some other growth factor. The curve grows slowly at first, but then grows quickly to an inflection point, followed by a levelling off as the product reaches market saturation, to produce a sigmoidal (s-shaped) function. Appendix figure VII.1 (projected Australian car ownership per head) is an example of a logistic curve.

Logistic function *See* **Logistic curve**.

Long-term passenger numbers The number of Australian resident departures and foreign passenger arrivals undertaking travel for a period of more than 12 months. *See also* **short-term passenger numbers.**

Low-heat-rejection engine An engine system in which the combustion heat loss to the coolant is minimised. This results in a greater proportion of the thermal value of the fuel being converted to useful work. Low-heat-rejection engines are also commonly referred to as 'adiabatic engines'.

Mach In the case of an aircraft in flight, it is the ratio of the velocity of the aircraft in air, to the velocity of sound in air, at the same temperature and atmospheric pressure. Mach numbers less than 1 indicate subsonic velocity; those greater than 1, supersonic velocity.

Marginal cost (of reducing greenhouse emissions) The additional social cost incurred when greenhouse emissions (measured in CO_2 equivalents) are reduced by one (technically infinitesimal) unit or decrement. Marginal costs in this Report are based on differences in intensity (application) of an abatement measure in a snapshot year (explained fully in chapter 2). Costs are expressed as the present value in 1995–96 Australian dollars of economic costs (including where possible changes in consumer surplus) net of the value of changes in associated externalities such as congestion. Present values are determined using a real discount rate of 10 per cent per annum. *See also* **incremental cost, social cost.**

Mean block speed Kilometres flown by an aircraft on scheduled regular public transport routes divided by hours flown on scheduled regular public transport routes, expressed in kilometres per hour. *See also* **average aircraft utilisation.**

Measure A specific action or set of actions implemented as part of a deliberate government policy to reduce greenhouse emissions. (The term 'instrument' is used as a synonym throughout this Report.) Because a measure represents a deliberate policy response over and above what would have occurred in the normal course of events, its effects are not normally included as part of basecase projections of emissions (except for measures already in place). A set of measures (e.g. a carbon tax, increased urban parking charges, and reduced fares on urban public transport) may be used to implement a strategy such as reduced usage of cars for commuting to work. The term strategy has not generally been used in this Report. *See also* **basecase**.

Miles per gallon (MPG) Measure of fuel efficiency with the following conversion into metric units:

Imperial: 1 MPG = 0.354 km per litre
USA: 1 MPG = 0.425 km per litre

Mobile sources Sources of greenhouse gas emissions associated with mobile fuel combustion activities, regardless of the sector or industry on whose behalf the activity is undertaken. The following source categories are included in this Report:

- **Air transport** Includes all civil and military aviation activities.
  - **Domestic civil aviation** Commercial airline and general aviation (such as private, agricultural commuter and charter) services, for both freight and passenger movements within Australian territory.
  - **International aviation** Includes international air freight and passenger movements accomplished using fuel purchased in Australia.
- **Road transport** All activity (on-road and off-road) by vehicles registered for road use (with a motor vehicle registration authority), except vehicles belonging to the Australian Defence Forces. Emissions by military vehicles and vehicles used exclusively for off-road purposes (such as competition motorcycles, forklifts and tractors) are accounted for in other source categories below. The road transport

sector is sub-divided into categories based on the vehicle definitions contained in Australian Design Rules for Motor Vehicles and Trailers.

- **Passenger cars** All passenger vehicles which carry less than 10 passengers (including the driver). These consist of cars, station wagons, taxis, minibuses, four-wheel drive passenger vehicles and forward control passenger vehicles. In this Report, petrol-fuelled cars are subdivided by vehicle age into year of manufacture categories: pre-1976, 1976–1980, 1981–1985, and post-1985.
- **Light goods vehicles** Trucks and light commercial vehicles designed to carry goods and not exceeding 3.5 tonnes gross vehicle mass. These include utilities, panel vans, cab chassis and forward control load carrying vehicles. The equipment carried on special purpose vehicles having little freight carrying capacity (such as ambulances, fire trucks and mobile cranes) is regarded as being equivalent to goods for the purposes of vehicle definitions.
- **Medium goods vehicles** Goods vehicles (including rigid trucks, articulated trucks and special purpose vehicles) with gross vehicle mass exceeding 3.5 tonnes but not exceeding 12.0 tonnes.
- **Heavy goods vehicles** Goods vehicles (rigid trucks, articulated trucks and special purpose vehicles) exceeding 12.0 tonnes gross vehicle mass.
- **Buses** Passenger vehicles with 10 or more seats, including that of the driver.
- **Motorcycles** 2-wheeled and 3-wheeled motor vehicles.

• **Rail transport** Includes non-electric railway services for both passenger and freight movement. Emissions due to the generation of electricity for electric railways are not included in end-use emissions estimates given in this Report.

• **Marine transport** Includes all civil maritime activity.

- **Domestic marine transport** Coastal shipping (freight and cruises), interstate and urban ferry services, commercial fishing, and small pleasure craft movements.
- **International shipping** includes passenger and freight movement by seagoing ships (of all flags) accomplished using marine bunker fuel purchased in Australia.

- **Military transport** All activity by military land vehicles, aircraft and ships.
- **Other mobile sources** Include unregistered recreational or competition vehicles (such as trail bikes and racing cars), farm and forestry equipment (such as tractors and harvesters), industrial equipment (used by the manufacturing, construction and mining sectors and which includes vehicles such as forklifts, bulldozers and quarry trucks) and miscellaneous mobile utility engines (such as lawn-mowers and chainsaws).

Mode The broad category of transport used; for example, road, rail, aviation and shipping.

Motorcycle *See* **mobile sources—road transport.**

National Greenhouse Response Strategy (NGRS) Based on the Interim Planning Target, and endorsed by all Australian governments on 7 December 1992, the NGRS contains mainly 'no regrets' measures.

Natural gas (NG) Consists primarily of methane (about 90 per cent, with traces of other gaseous hydrocarbons, nitrogen and CO_2) and occurs naturally in underground deposits. As a transport fuel, it is generally used in compressed or liquefied form.

Natural greenhouse effect The warming effect of greenhouse gases in the atmosphere that are not of human origin.

Net calorific value (NCV) The gross calorific value of a fuel less the heat of vaporisation (at 25°C and constant volume) of the water present in the fuel and that formed during combustion. NCV is also known as lower heating value. The International Energy Agency (IEA) generally reports energy data in terms of NCV, whereas Australian energy data is typically reported in GCVs. The IEA assumes that lower heating values are 5 per cent lower than higher heating values for oil and coal, and 10 per cent lower for natural gas.

'No regrets' measure Abatement measures that reduce greenhouse emissions or increase carbon sinks, but whose social cost is zero or negative.

Noxious emissions Term used for emissions that contribute to air pollution in the local environment where they are emitted. Gases emitted from transport that result in adverse effects on human health include oxides of nitrogen (NO_x) other than nitrous oxide, sulphur dioxide, carbon monoxide, volatile organic compounds, and particulates.

Octane rating The quality of a particular petrol mixture is rated according to its research octane number (RON), or anti-knock index. Petrol with a high octane number burns more slowly and smoothly, and is a more effective fuel. The RON is obtained by compressing the knock (irregular explosions in the cylinder during combustion) characteristics of a fuel with those of two reference compounds, iso-octane (C_8H_{18}) and heptane (C_7H_{16}). Iso-octane is considered to have very good anti-knock qualities and is assigned an octane number of 100. Heptane has poor anti-knock qualities and is assigned an octane number of zero. Petrol with the same anti-knock characteristics as a mixture of 95 per cent iso-octane and 5 per cent heptane would be rated as 95 octane. Australian regular unleaded petrol has RON of between 91 and 93. Premium unleaded is between 95 and 98 octane, and leaded petrol is about 97 octane.

Opportunity cost *See* **Economic cost**.

Other trucks Include specialist vehicles or vehicles fitted with special purpose equipment, and having little or no significant load carrying capacity; for example ambulances, mobile cranes, cherry pickers, fire trucks.

Oxidation The process by which fuel is combined with oxygen by burning. The proportion of fuel burnt is referred to as the oxidised component or oxidation factor, while a non-oxidised component results in solid combustion products such as soot and ash.

Oxidation factor The proportion of the fuel oxidised during combustion.

Partial equilibrium analysis Adopted as the method of analysis in this Report, partial equilibrium analysis refers to the determination of equilibrium positions or outcomes of policy measures within only a part of the economy (such as an individual consumer or the transport sector), on the assumption that effects on other markets are negligible. Relationships (including feedbacks) with other sectors or markets are ignored. No account would be taken, for example, of employment effects in the car manufacturing industry if motorists scrapped older, fuel-inefficient vehicles in response to a carbon tax. *See also* **general equilibrium analysis**.

Passenger cars *See* **mobile sources—road transport.**

Passenger-kilometres (pkm) The product of the number of passengers in a given vehicle on a given journey and the distance (in kilometres) travelled by that vehicle on that journey.

Passing loop A siding that allows a train to pull off the line that it is travelling on, to allow another train to pass. The length of passing loops determines the length of trains using the track.

Pavement loading Contribution of a class of vehicle (e.g. cars, articulated trucks) to the 'wear and tear' of the road pavement. It is the product of vehicle-kilometres travelled and equivalent standard axle loading (ESAL) for the vehicle class. *See also* **equivalent standard axle loading.**

Petrol A derivative of petroleum used as fuel in spark ignition internal combustion engines other than aviation piston engines. Also known as automotive gasoline or gas in North America, it is a complex mixture of about 200 hydrocarbons in the range C_4 to C_{12}, including paraffins such as hexane (C_6H_{14}) and octane (C_8H_{18}), olefins such as hexene (C_6H_{12}), and aromatics such as benzene (C_6H_6) and toluene (C_7H_8). Both leaded and unleaded petrol are sold in Australia. The leaded form (normally containing the additive tetraethyl lead, $C_8H_{20}Pb$, to increase the octane rating of the fuel) is used in motor vehicles manufactured prior to 1986, and the unleaded form is used mainly in post-1985 vehicles. The net energy value of petrol is about 31.9 megajoules per litre. Because a large proportion of abatement measures analysed were completed before the end of the financial year, the BTCE used an estimate of 74.2 cents per litre as the average retail price of leaded petrol in Australia for 1995-96. *See also* **diesel fuel, octane rating, petroleum.**

Petroleum Also known as crude oil, petroleum is a primary fossil fuel found in underground deposits throughout the world and contains up to 300 compounds of hydrogen and carbon as well as sulphur and nitrogen. Its elemental composition is fairly constant and includes the following percentages of carbon (83 to 87), hydrogen (10 to 14), nitrogen (0.1 to 2), oxygen (0.05 to 1.5), and sulphur (0.05 to 6). *See also* **diesel fuel, petrol.**

Pigovian/Pigouvian tax In the presence of a negative externality such as pollution, a corrective tax that equals the marginal cost imposed by a polluter on society in order to produce an economically efficient (Pareto optimal) allocation of resources in the partial equilibrium sense where price equals social marginal cost. So named because the concept is attributed to the economist A.C. Pigou.

Pilots' dispute Major industrial dispute which occurred between Australian domestic airlines and their pilots during the period between the second quarter of 1989 and the third quarter of 1990 inclusive.

Primary energy/ fuel A non-renewable energy resource in the ground which, by extraction, refining and delivery, can become an economically useful energy or fuel. It is rare that a primary energy source can be used without some refining before use. Natural gas and coal are primary energy fuels; electricity is not. *See also* **fossil fuel.**

Private cost *See* **social cost.**

Producer surplus The excess of total receipts faced by a producer (a firm or an individual) supplying a good or service over the total avoidable cost of supplying that level of good or service. *See also* **consumer surplus, economic cost.**

Propfan *See* **unducted fan engines.**

Propulsion system The combination of all components which are required to propel a vehicle, e.g. engine, accessories and engine-control system, fuel system, protection devices, inlets and cooling systems.

Public cost *See* **social cost.**

Pumping loss Engine power output can be decomposed to recognise engine energy losses. There are two general types of engine energy losses: (i) thermodynamic efficiency and heat recovery, and (ii) engine friction both mechanical and aerodynamic. The phrase 'pumping loss' refers to aerodynamic engine friction.

Radiative forcing A change in the energy available to the global earth/atmosphere system, measured in watts per square metre. A positive radiative forcing tends to warm the surface of the earth and a negative one cools the surface. The radiative forcing is normally quoted as a global and annual mean value. Radiative effects of greenhouse gases relative to that of an equal mass of CO_2 can be represented as global warming potentials.

Rate of time preference *See* **discount rate**.

Rebound effect Greenhouse abatement measures that increase the efficiency of use of fuel will reduce operating costs faced by an emitter such as a car driver. Where cost is a determinant of kilometres travelled, there may be a 'rebound effect', where the fall in vehicle operating costs will induce additional travel as drivers adjust their travel behaviour, or change jobs or residential location.

Reformulated gasoline (RFG) A variety of improved (unleaded) petrol blends which are being developed to improve air quality. RFGs typically have added oxygen and a reduced proportion of highly volatile compounds.

Resources A generic term for factors or means of production used in a firm or economy to produce or distribute goods or services. They are traditionally classified into land, labour and capital. It is the intrinsic scarcity of resources that determines their value in exchange, and hence costs to users of resources. The efficiency with which resources are allocated within an economy determines the overall amount of goods and services that can be produced, and hence the level of social welfare. *See also* **economic cost, welfare**.

Revenue recycling The ultimate reduction in greenhouse gases achieved by a measure such as a carbon tax will depend on what is done with the revenue collected. Revenue recycling is discussed in chapter 2 of this Report.

Rigid trucks Rigid trucks usually refer to non-articulated vehicles exceeding 3.5 tonnes gross vehicle mass, constructed primarily for the carriage of goods. Included are normal rigid trucks with a towbar, drawbar or other non-articulated coupling on the rear of the vehicle for use with a trailer or dolly.

Rolling resistance The set of internal forces tending to slow down a moving vehicle. Rolling resistance forces include the friction within the axles, wheel bearing friction and friction between the tyres and the road.

Running losses Evaporative emissions of hydrocarbons from the vehicle fuel system, occurring while the vehicle is being driven. *See also* **diurnal emissions, evaporative emissions, hot soak.**

Seat-kilometre Available seat-kilometres (number of seats offered multiplied by the distance flown) are used as a measure of capacity for a single flight, an airline or industry wide.

Short-term passenger numbers The number of Australian resident departures and foreign passenger arrivals undertaking travel for a period of less than twelve months. *See also* **long-term passenger numbers.**

Sink *See* **carbon sink**.

Snapshot year Taken in this Report to mean the years 2000, 2005, 2010 and 2015. Snapshot years are used to illustrate changes in costs between discrete points of time.

Social cost Social costs of some activity are those borne by society as a whole. They are the sum of the costs of resources used by individuals in some activity (private costs), and the value of any loss in welfare or increase in costs which that activity causes to other individuals (public cost, or externality). If the opportunity costs of resources are correctly reflected in their market price, then social costs differ from private costs by the amount of the value of any externalities. Cost–benefit analysis is based on social costs and benefits. *See also* **externality, social discount rate, transfer payment.**

Social discount rate Where the present value of a project or proposal is being considered from the perspective of the community as a whole, as in cost–benefit analysis, it is appropriate to use a social discount rate rather than a discount rate that reflects only private individuals' rate of time preference. Two major approaches, the Social Opportunity Cost of Capital and the Social (Marginal) Rate of Time Preference, are usually considered in the literature, but rarely pursued rigorously in practice because of the difficult judgemental and analytical issues involved. *See also* **discount rate, externality, social cost.**

Specific fuel consumption Fuel consumed per unit of power output, usually expressed as mass or volume per unit power per unit time.

Stratosphere The earth's atmosphere above the troposphere, about 8 kilometres high at the poles and about 16 kilometres high at the equator, extending about 80 kilometres up to where the ionosphere begins. The stratosphere has little moisture and temperature does not vary with height.

Supersonic aircraft Aircraft that can travel faster through the air than the speed of sound.

Supercharging Engine-driven compressor that forces fuel mixture into the cylinders at greater than atmospheric pressure. Three main advantages: (i) it enables a relatively small engine to produce high power; (ii) it does so without adding substantially to the weight of the engine; and (iii) it does not add appreciably to overall fuel consumption unless the additional power is used.

Synthetic households Households described in terms of a number of socioeconomic characteristics that are used in the ITS/BTCE model **(appendix VI)** to represent groups of real households.

Tonne kilometres (tkm) The product of the weight of the freight of a given vehicle on a given haul and the distance of that haul. Tonnage and distance are combined to standardise for the variety of freight tasks, ranging from many small items carried over short distances to bulk freight hauled over long distances, when aggregating freight task levels.

Toronto target A plan adopted by the Changing Atmosphere: Implications for Global Security Conference, held in Toronto in 1988, calling on governments to stabilise national greenhouse emissions at 1988 levels by the year 2000, and to reduce them by [a further] 20 per cent by 2005.

Tradable permits Tradable permits are transferable private property rights. Under an emissions trading scheme, emitters are given permits to emit a specified quantity (a right or quota) of greenhouse gases and have the option of buying or selling permits in the marketplace. When traded on a national market, permit prices are established that reveal the costs of marginal emissions. These marginal costs should be equal in theory to those set under a Pigovian tax on greenhouse emissions.

Transfer payment Payments which are not made in return for some productive service. For example, unemployment benefits provided by government to those without work are a transfer, via government, from those who pay income or other taxes. Taxation is also a transfer payment, to the government. From the point of view of society as a whole, therefore, transfer payments represent a redistribution of benefits and costs. Because total social welfare remains unchanged, transfer payments are usually identified (as part of equity analysis), but not included in the overall calculation of social costs or benefits. *See also* **social cost.**

Transport mode *See* **mode.**

Trip linking Rather than making two separate trips, a traveller may combine them. For example, a child may be dropped off at school on the way to work rather than separate journeys being undertaken to school and work. The concept usually implies a reduction in time taken or fuel used because of the linking of the trips.

Troposphere The atmosphere above the earth's surface up to the region where temperature ceases to decrease with height (the stratosphere): about 16 km at the equator. This upper boundary is termed the tropopause. *See also* **stratosphere.**

TRUCKMOD A spreadsheet model of the Australian commercial vehicle (truck and light commercial vehicle) fleet developed by the BTCE to simulate fleet characteristics over time, including factors such as number of vehicles, age, scrapping rates, average fuel efficiency, and emissions **(appendix VIII)**.

Turbocharger Compressor unit driven by a small turbine rotated at high speed by the engine's exhaust gases. The turbine is used to compress the fuel mixture to achieve the same effects as the supercharger.

Turbocompounding Exhaust gas driven second or 'compound' turbine, usually downstream of the turbocharger, which is connected to the crankshaft via a hydraulic coupling and reduction gearing.

Turbofan engines The most important form of propulsion for all except slow aeroplanes (say below 600 km/h). A turbofan comprises gas turbine core engine plus extra turbine stages driving a large diameter fan ducting very large propulsive air flow around the core engine and generating most of the thrust. Using the large fans to accelerate more air around the core engine, more thrust is generated per unit of fuel consumed.

Turbojet is the simplest form of gas turbine, comprising compressor, combustion chamber and turbine, the latter extracting only just enough energy from gas flow to drive the compressor. The engine produces forward propulsion by ejecting the exhaust gases through a constricting propelling nozzle.

Ultra high-bypass turbofan Potential improved version of a high-bypass turbofan engine that can increase the propulsion efficiency by increasing the bypass ratio.

Unducted fan (propfan) engines Advanced propeller for use at high speed, characterised by having 6 to 12 blades each being thin, sharp edged, lenticular (double-convex) and curved scimitar in shape. The propfan offers greater efficiency at high speed than conventional propellers because of its shape.

Unlinked Refers to the recording separately of every segment of a trip (undertaken by a distinct mode of transport) as opposed to a linked trip, which refers to a complete journey from origin to destination, possibly involving several modes.

Vehicle utilisation level The total distance travelled by a given vehicle in a given time period (for example, kilometres per year).

Vintage A cohort of vehicles manufactured in the same year. AVMOD **(appendix IX)**, CARMOD **(appendix VII)** and TRUCKMOD **(appendix VIII)** are models based on vintages of aircraft, cars and trucks respectively. Vintage models facilitate disaggregated analysis of the overall effect on a fleet of vehicles of a greenhouse abatement measure or other government policies.

Volatile organic compound (VOC) Most of the VOC exhaust emissions from conventional vehicles are composed of hydrocarbons and carbonyl compounds. Carbonyls (which include aldehydes and ketones) are very reactive compounds that consist of a hydrocarbon structure with one or more of the carbon atoms double bonded to an oxygen atom. VOCs from petrol include formaldehyde (a carbonyl, H_2CO), benzene (an aromatic hydrocarbon, C_6H_6), and butadiene (an alkene, C_4H_6). VOC emissions from alcohol-fuelled vehicles contain a greater proportion of aldehydes.

Volumetric efficiency Extent to which the cylinder of an engine is completely filled by the incoming charge following an exhaust stroke. A measure of the ability of an engine to breathe freely. Note that the volumetric efficiency is a ratio of masses, not of volumes.

Welfare The term welfare (or social welfare) is used throughout this Report in its economic sense of the effect of a greenhouse abatement measure on the efficiency of allocation of resources in the community.

Resources are allocated most efficiently (referred to as Pareto-optimal) when it is not possible to change the allocation of resources between economic agents (individuals, firms, etc.) without making someone worse off. *See also* **resources**.

Zone centroid The geographic centre of a zone used in a transport network model.

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AAA	Australian Automotive Association
ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ACCI	Australian Chamber of Commerce and Industry
ACTA	Australian City Transit Association
AGPS	Australian Government Publishing Service
AIP	Australian Institute of Petroleum
ARRB	Australian Road Research Board
ATRF	Australian Transport Research Forum
BIE	Bureau of Industry Economics
BTCE	Bureau of Transport and Communications Economics
BTE	Bureau of Transport Economics
CBCS	Commonwealth Bureau of Census and Statistics
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DASETT	Department of the Arts, Sport, the Environment, Tourism and Territories
DEST	Department of the Environment, Sport and Territories
DME	Department of Minerals and Energy of New South Wales
DOT	Department of Transport
DOTC	Department of of Transport and Communications
DPIE	Department of Primary Industries and Energy
ECMT	European Conference of Ministers of Transport
EPA	Environment Protection Agency (NSW)
EPAV	Environment Protection Authority (Victoria)
ERDC	Energy Research and Development Corporation

ESAA	Electricity Supply Association of Australia
FORS	Federal Office of Road Safety
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ITA	Institute of Air Transport
ITS	Institute of Transport Studies
NASA	National Aeronautics and Space Administration
NGAC	National Greenhouse Advisory Committee
NGGIC	National Greenhouse Gas Inventory Committee
NTPT	National Transport Planning Taskforce
OECD	Organisation for Economic Cooperation and Development
RIC	Railway Industry Council
RTA	Roads and Traffic Authority, New South Wales
SCOT	Standing Committee on Transport
SPCC	State Pollution Control Commission
STSG	State Transport Study Group (NSW)
UNEP	United Nations Environment Programme
VIC ROADS	Roads Corporation of Victoria
WMO	World Meteorological Organisation
WRI	World Resources Institute

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ABBREVIATIONS

..	not applicable
1996–97	Australian financial year 1 July 1996 to 30 June 1997
AADT	annual average daily traffic
ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ACCI	Australian Chamber of Commerce and Industry
ACS	Australian Customs Service
ACT	Australian Capital Territory
Adel	Adelaide
ADIPG	Australian Draft Inventory Preparation Group
ADO	automotive diesel oil
ADR	Australian Design Rule
AEC	Australian Environment Council
AGA	Australian Gas Association
AIP	Australian Institute of Petroleum
ALPGA	Australian Liquefied Petroleum Gas Association
ANMA	Australian National Maritime Association
ARRB	Australian Road Research Board Ltd
AS	Australian Standard
AT	articulated trucks
ATRF	Australian Transport Research Forum
avgas	aviation gasoline
AVMOD	BTCE aviation model
avtur	aviation turbine fuel
billion	1 000 000 000 (Australian usage)
Bris	Brisbane
BTCE	Bureau of Transport and Communications Economics

BTR	Bureau of Tourism Research
C	carbon
°C	degrees Celsius
$CaCO_3$	calcium carbonate
CAFE	corporate average fuel economy
CAI	Current Annual Increment
Canb	Canberra
CARB	California Air Resources Board
CARMOD	BTCE car model
CBCS	Commonwealth Bureau of Census and Statistics
CBD	Central Business District
CDROM	compact disk, read only memory (a storage medium for computers)
CEPA	Commonwealth Environment Protection Agency
CFC-12	a chlorofluorocarbon used in vehicle air-conditioners
CFCs	chlorofluorocarbons
CFI	central fuel injection
CH_4	methane
C_2H_5OH	ethanol
C_3H_6	propylene
C_3H_8	propane
C_4H_{10}	butane
C_4H_6	butadiene
C_6H_{12}	hexene
C_6H_{14}	hexane
C_6H_6	benzene
C_7H_8	toluene
C_8H_{18}	octane
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
COP1	(FCCC) First Conference of the Parties
COP2	(FCCC) Second Conference of the Parties
COP3	(FCCC) Third Conference of the Parties
CORC	Cochrane-Orcutt estimation

CSIRO	Commonwealth Scientific and Industrial Research Organisation
CVT	continuously variable transmission
DASET	Department of the Arts, Sport, the Environment and Territories
DEST	Department of the Environment, Sport and Territories
DH	Durbin's h-statistic
DME	Department of Minerals and Energy of New South Wales
DOT	Department of Transport
DOTC	Department of Transport and Communications
DoTRD	Department of Transport and Regional Development
DPIE	Department of Primary Industries and Energy
DTC	Department of Transport and Communications
DW	Durbin–Watson d-statistic
DWT	deadweight tonnage
E10	a blend of petrol containing 10 per cent ethanol
ECMT	European Conference of Ministers of Transport
ECU	European Currency Unit
EM	Estimation Method
ENERGYMOD	BTCE fuel consumption and emissions model
ENSO	El Niño–Southern Oscillation
EPA	Environment Protection Authority (NSW)
EPAV	Environment Protection Authority (Victoria)
ERDC	Energy Research and Development Corporation
ESA	equivalent standard axle
ESD	Ecologically Sustainable Development strategy
FCAI	Federal Chamber of Automotive Industries
FCCC	Framework Convention on Climate Change
FCG	*Fuel Consumption Guide*
FCs	fluorocarbons
FE	fuel efficiency
FFV	flexible-fuel vehicle
FI	fuel intensity
FO	fuel oil
FORS	Federal Office of Road Safety
G7	Group of Seven major OECD economies
GCV	gross calorific value

GDP	gross domestic product
Gg	gigagram (10^9 grams), equal to a thousand tonnes
GJ	gigajoule (10^9 joules)
GWP	global warming potential
H	hydrogen
ha	hectare
HC	hydrocarbon
HCFCs	hydrochlorofluorocarbons
H_2CO	formaldehyde
HDM	World Bank's Highway Development and Maintenance Model
HDM-C	version of HDM-III modified by the BTCE and programmed in the C language
HDM-III	World Bank's Highway Development and Maintenance Model version III
HFCs	hydrofluorocarbons
HLF	hybrid laminar flow
H_2O	water (including water vapour)
I&M	inspection and maintenance
ICAO	International Civil Aviation Organisation
IDF	industrial diesel fuel
IEA	International Energy Agency
IMO	International Maritime Organisation
INC	Intergovernmental Negotiating Committee
IOP	iron ore production
IPCC	Intergovernmental Panel on Climate Change
IPT	interim planning target
IRI	International Roughness Index
ITA	Institut du Transport Aérien (Institute of Air Transport)
ITS	Institute of Transport Studies, University of Sydney
kg	kilogram
km	kilometre
L	litre
L/100 km	litres consumed per 100 km travelled
lbs	pounds weight
LCV	light commercial vehicle
LFC	laminar flow control

ln	natural logarithm
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MAB	Marginal Abatement Benefit
MAC	Marginal Abatement Cost
MAI	mean annual increment
MC	marginal cost
Mel	Melbourne
MJ	megajoule (million joules)
ML	megalitre (million litres)
MPC	marginal private cost
mpg	miles per gallon
MSC	marginal social cost
Mt	megatonnes (million tonnes)
MTS	Maximum Technology Scenario
MVC	Motor Vehicle Census
N_2	nitrogen gas
na	not available
NAASRA	National Association of Australian State Road Authorities
NAFC	national average fuel consumption
NCV	net calorific value
NFGDP	non-farm gross domestic product
NG	natural gas
NGAC	National Greenhouse Advisory Committee
NGGIC	National Greenhouse Gas Inventory Committee
NGRS	National Greenhouse Response Strategy
NHS	National Highway System
NIEIR	National Institute of Economic and Industry Research
NISE	National In-Service Emissions
NLF	natural laminar flow
NMVOC	non-methane volatile organic compound
N_2O	nitrous oxide
NO_x	oxides of nitrogen other than nitrous oxide
NPAC	National Plantations Advisory Committee
NRM	NAASRA roughness metre counts: a measure of roadway terminal roughness

NRMA	National Roads and Motorists Association
NSW	New South Wales
NT	Northern Territory
NTPT	National Transport Planning Taskforce
O	oxygen
O_3	ozone
OBD	on-board diagnostics
OD	origin–destination
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares Estimation
Per	Perth
PJ	petajoule (10^{15} joules)
pkm	passenger-kilometre
PVC	present value of a single planting cycle
PVS	present value of infinite planting cycle
Qld	Queensland
RAC	Resource Assessment Commission
RCEP	Royal Commission on Environmental Pollution
RFG	reformulated gasoline
RIAM	BTCE Road Infrastructure Assessment Model
RIC	Railway Industry Council
RONI	Road of National Importance
ROT	rigid and other trucks
RTA	Roads and Traffic Authority (NSW)
SA	South Australia
SAE	Society of Automotive Engineers (Melbourne)
skm/L	Seat-kilometres per litre
SMVU	Survey of Motor Vehicle Use
SN	structural number
SNC	modified structural number
SOCC	Social Opportunity Cost of Capital
SOCT	Social Opportunity Cost of Travel
SO_x	sulphur oxides
SRTP	Social Rate of Time Preference
Syd	Sydney
t	tonne

Tas	Tasmania
tkm	tonne-kilometre
TPC	Trade Practices Commission
UHB	ultra high-bypass (engines)
ULEV	Ultra-low Emission Vehicle (standard)
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
UPT	urban public transport
US	United States (of America)
USA	United States of America
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
Vic	Victoria
VIC ROADS	Roads Corporation, Victoria
vkt	vehicle-kilometres travelled
VOC	volatile organic compound; vehicle operating costs (chapter 16)
WA	Western Australia
WMO	World Meteorological Organisation
WRI	World Resources Institute