# Costs of Reducing Greenhouse Gas Emissions from Australian Cars: an Application of the BTCE CARMOD Model

## Working Paper

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Bureau of Transport and Communications Economics

# WORKING PAPER 24

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## FOREWORD

In his 21 December 1992 Statement on the Environment, the then Prime Minister announced that the Bureau of Transport and Communications Economics (BTCE) would provide a comprehensive analysis of the range of possible measures for reducing greenhouse gas emissions from the transport sector. The project is scheduled for completion in mid-1996.

In March 1995 the BTCE published base case projections of emissions of greenhouse gases as Report 88, *Greenhouse Gas Emissions from Australian Transport: Long Term Projections.* Work since then has focussed on estimating the marginal costs of reducing emissions from base case levels. Initial results for a set of policy instruments were presented at a 'work in progress' seminar in Canberra on 7 December 1995.

Policy instruments evaluated in this working paper are the accelerated implementation of fuel efficiency technology for new cars, the accelerated scrappage of highly polluting vehicles, tighter emission standards for new cars, and mandatory regular tuning of vehicles. Analysis of such policy options relies on the CARMOD model of the dynamics of the Australian car fleet.

CARMOD was developed by David Cosgrove under the direction of Dr David Gargett. Edwina Heyhoe, Alison Bailie and Marion Stefaniw (under the direction of Joe Motha) used the model to analyse the potential emission abatement measures affecting passenger vehicles. Belinda Jackson edited the manuscript.

Dr Leo Dobes
Research Manager

Bureau of Transport and Communications Economics
Canberra
April 1996

## ABSTRACT


The BTCE has developed a model of the dynamics of the Australian car fleet. Called CARMOD, it incorporates a number of policy simulators which can be used to examine policy options aimed at improving the performance of the car fleet in terms of fuel efficiency or emissions.

Four potential policies for greenhouse gas abatement are analysed in this paper using CARMOD: the accelerated introduction of fuel efficiency technology for new cars, new emission control technologies, mandatory car servicing and accelerated scrappage of older cars. Comparisons of the marginal costs of abatement in the 'snapshot' years 2000, 2005, 2010 and 2015 indicate that the different policies would involve markedly different costs.

The results should be interpreted with extreme caution. The four policies analysed are but a few of numerous policies available within the transport sector. Defensible policy formulation would require comparisons with costs of a wide range of policy options not only in the transport sector, but also in other areas of the economy such as industry or the residential sector.

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# CHAPTER 1 INTRODUCTION

The Bureau of Transport and Communications Economics (BTCE) is increasingly involved with research into issues relevant to longer term changes in the Australian transport sector; including the reduction of greenhouse gas emissions from transport vehicles. Transport is associated with relatively long-lived fleets of vehicles, so the ability to look a long way into the future depends on the ability to model the long-term dynamics of fleet replacement. Current model Australian passenger vehicles remain in the fleet for around 20 years on average before being scrapped, and the average age of the car fleet is about 10 years.

BTCE (1995) used a rudimentary fleet model to produce forecasts of greenhouse emissions from the Australian car fleet from 1996 to 2015. This working paper describes a more detailed model of the car fleet (CARMOD) developed by the BTCE as part of its greenhouse project.

The forecasting model used in BTCE (1995) was lacking in several respects. It took no account of deterioration of vehicles as they aged—either fuel efficiency decreases or pollutant emission increases. Also, no account was taken of the effects of likely increases in congestion in the major Australian cities. Furthermore, the specification of the car scrappage equations was extremely rudimentary. CARMOD has corrected these three major deficiencies, and improved the base case projections of fuel use and emissions by the car fleet. Revised base case projections are presented in appendix II.

CARMOD was also developed to facilitate detailed policy simulations. The model now incorporates a large number of policy simulators (or scenario input variables) that can be used to assess the effects of different options for mitigating greenhouse gas or pollutant emissions from the Australian car fleet. The policy simulators are described in chapter 3.

Examples of specific policies are simulated and costed in chapters 4 to 7 (accelerated fuel efficiency standards, new emission control technology, mandatory car servicing, and accelerated scrappage of older cars). The policies are evaluated as examples only, not as recommendations.

To represent the total greenhouse effect of the various gases emitted by cars, emissions are expressed in terms of a common unit—carbon dioxide ($CO_2$) equivalent emissions. Using the global warming potential (GWP) of each gas, an index of the warming effect of a gas relative to $CO_2$, allows the calculation of $CO_2$ equivalent emissions from vehicles. The GWP values employed in this working paper are based on conventions adopted by the Intergovernmental Panel on Climate Change (IPCC) for a 100 year horizon (see appendix I).

Marginal costs associated with introducing the emission abatement measures have been estimated for each of the policy simulations. The estimated costs are expressed as dollars per tonne of $CO_2$ equivalent greenhouse gas reduction.

The policy measures are based on the conventions that:

- in presenting the results, 'snapshot' years 2000, 2005, 2010 and 2015 have been used for ease of presentation, while providing sufficient information on dynamic aspects. Comparison of costs in 2000 and 2015, for example, provides a good indication of the relative suitability of an instrument in the short or the long term. Snapshot years are not intended to suggest targets;
- to ensure valid comparisons between instruments which can be imposed effectively in the short term (for example a carbon tax) and those that require long lead times (for example new technology), all emission reductions (resulting from an abatement measure) are calculated as the cumulative reduction in $CO_2$ equivalent emissions over the years from 1996 to 2000, 2005, 2010, or 2015. Marginal changes in the 'snapshot' years 2000, 2005, 2010 and 2015 are therefore marginal changes in cumulative emissions up to and including the snapshot year;
- the estimates presented in this working paper are 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 working paper to avoid confusion;
- the analysis throughout this working paper focuses on end-use emissions, that is, emissions generated by the vehicle itself. It excludes emissions that occur during the production or distribution of fuels, and any emissions generated in the manufacture of vehicles or building, repair or maintenance of infrastructure. Inclusion of emissions generated outside the transport sector itself risks double counting in comparisons with other sectors. Inclusion would also require a full carbon-budgeting approach to ensure that offsetting emission reductions (for example use of recycled car bodies in steel manufacture) were taken fully into account;
- costs are expressed in 1995–96 Australian dollars;
- costs are discounted to net present (1995-96) values using a 10 per cent discount rate, and the stream of these discounted costs is summed to get 'total cost'.

Details of other assumptions specific to individual policy instruments are given in the individual chapters.

# CHAPTER 2 BASE CASE PROJECTIONS OF PASSENGER CAR EMISSIONS

## MODELLING THE DYNAMICS OF THE AUSTRALIAN CAR FLEET

Automobiles are durable goods. Most vehicles in the fleet at any time have been purchased in previous years. 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 a 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 aging and scrappage.

In 1995, a rudimentary model was developed to estimate future emissions from the Australian car fleet for BTCE Report 88, *Greenhouse Gas Emissions from Australian Transport: Long-term Projections*. Since the publication of Report 88 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 Report 88, 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 the model 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.

The changes made to the model allow not only for a greater range of policy simulations, but also have the potential to significantly alter base case projections of car fleet emissions. This chapter provides an overview of the

BTCE car fleet model (CARMOD), describes the modifications made to the earlier version, and presents revised base case projections.

Importantly, Report 88 found that car fleet emissions between 1995 and 2015 are expected to change only slightly from year to year, resulting in an overall decline of about 10 per cent over the period. The revised base case (using CARMOD) again expects car emissions to change 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:

$$\text{Fuel Consumption} = \frac{\text{Vehicles}}{\text{Population}} \times \text{Population} \times \text{VKT} \times \frac{\text{Average fuel intensity}}{100}$$

| (litres) | (cars per '000 persons) | ('000 persons) | (km per car) | (litres per km) |
|---|---|---|---|---|

*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/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; that is, the mass of $CO_2$ emissions that would give an equivalent warming effect to the actual mixture of emissions. For example, per gram, methane is over 20 times more efficient as a greenhouse gas than $CO_2$. This global warming potential approach is very approximate (see appendix I), but it is useful for illustrating changes across all gases emitted. Total $CO_2$ equivalent greenhouse gas emissions are calculated for the car fleet using the GWP indices presented in appendix I.

The estimation methods for each of the components of the above equation are explained separately below.

**Motor vehicle ownership**

A key aspect of the model is the projection of vehicles per person. The number of cars per thousand population for Australia has been 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.

In a review of overseas experience, Gruebler and Nakicenovic (1991) find that in each of 12 developed countries studied, a logistic formulation fits the data extremely well. Saturation rates are in the range of 550-700 cars per thousand population in North America, 300-550 in Europe and 200-250 in Japan. Some of these countries have already reached saturation; others are approaching it. Gruebler and Nakicenovic derive a range of 440-550 for the Australian value of the saturation level.

The basic form of the logistic equation relating cars per thousand population (*MVPER*) to time (*t*) is the following:

$$MVPER = k \;/\; (1 + ae^{-bt})$$

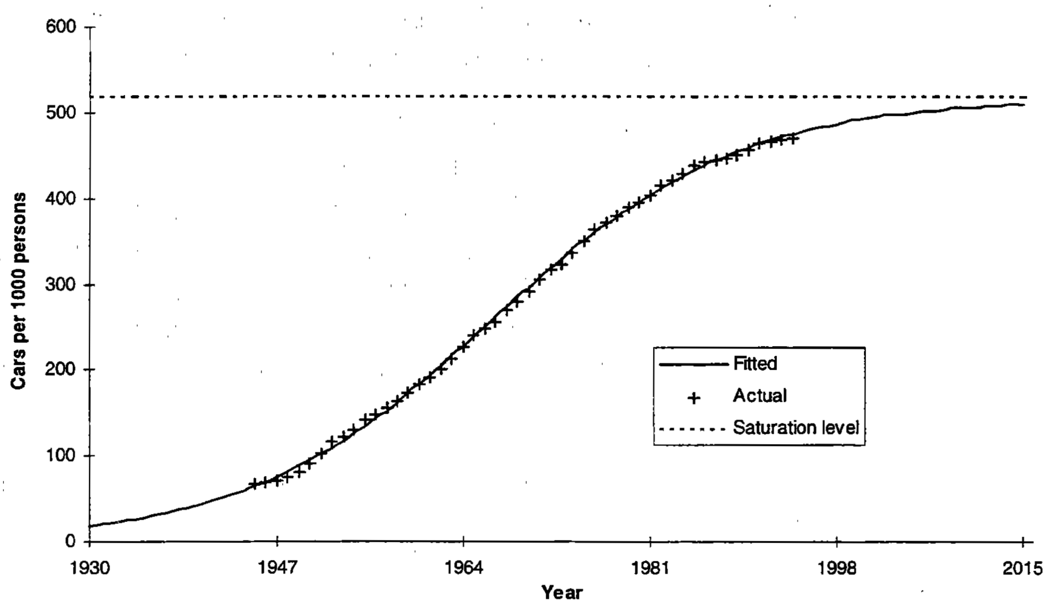
where $k$ is the saturation level of the logistic function, or upper bound on cars per 1000 population; $a$ and $b$ are constants. The value of $\ln(a)/b$ gives the time of the inflection point (that is, the point half way to saturation for a symmetric logistic function).

Using data on Australian vehicle populations from the Survey of Motor Vehicle Use (SMVU) (ABS 1993a and earlier) and Motor Vehicle Census (MVC) (ABS 1995 and earlier), the best fit of the logistic curve to the actual values was obtained with an estimated saturation level of around 520.

The logistic form was fit to the data over two periods: 1945 to 1994, and a restricted data set of 1958 to 1985. The latter fit was to allow for possible anomalies due to the post-war years, to sharp rises in car prices in 1986, and to vehicle type definition changes within motor vehicle registry statistics after 1991. The two estimated equations found to have the best fits over the respective periods are presented in table 2.1. Fitting the curve over the restricted data set did not significantly alter the logistic obtained, and equation (1) is thus used as the model default. A likely range for the saturation level of the Australian car fleet was obtained by fitting logistic curves using different saturation rates, and assessing the closeness of fit to the data. Values for $k$ of between 490 and 530 cars per thousand persons give logistic curves that diverge from the 1994 data point by less than 2 per cent.

Figure 2.1 shows the logistic form assumed to hold for future levels of Australian car ownership, which is currently about 470 vehicles per thousand people and is projected to level off at around 510 by early next century.

FIGURE 2.1 PROJECTED AUSTRALIAN MOTOR VEHICLE OWNERSHIP




*Sources* BTCE estimates; BTCE (1995); ABS (1995, 1993a and earlier).

TABLE 2.1 ESTIMATED LOGISTIC CURVE FOR CARS PER THOUSAND POPULATION, AUSTRALIA

| | |
|---|---|
| Dependent variable: | *MVPER* (Cars per thousand persons) |
| Form of equation: | $MVPER = k / (1 + ae^{-bt})$ |

where, $k$ is the saturation level, estimated as
(1) 516 cars per thousand population
(2) 524 cars per thousand population

| | |
|---|---|
| Estimation method: | Iterative Non-linear Least Squares |
| Estimation period: | (1) 1944-45 to 1993-94 (t=1 in 1944-45)<br>(2) 1957-58 to 1984-85 (t=1 in 1944-45) |
| Adjusted R squared: | (1) 0.9996<br>(2) 0.9994 |

| *Parameter* | *Estimates:* | *(1)* | *(2)* |
|---|---|---|---|
| a | | 7.65 | 7.92 |
| b | | 0.0896 | 0.0890 |

*Sources* BTCE estimates; BTCE (1995); ABS (1995 and earlier, 1994a and earlier, 1994b, 1994d, 1993a and earlier); CBCS (1973).

Using such a logistic function to represent cars per thousand population produces forecasts of vehicle ownership which depends only on time. However, the parameters *k, a* and *b* are inputs to the model and can be readily changed to suit scenarios dealing with future changes to the underlying logistic trend.

It is also possible to incorporate further explanatory variables in the logistic formulation. For example, functions of the form:

$$MVPER = k\ /\ (1 + ae^{-bt} + cI + dP)$$

can be fitted to the data, where $I$ is an income variable (such as real GDP) and $P$ is a price variable (such as the real price of new cars). Furthermore, it is possible to directly input (exogenously) any assumed level for total car stock. The model will then automatically estimate the probable fleet structure that would attain that level.

### *Scrappage*

Once the total vehicle stock for a particular year has been determined by the above procedure, the number of new cars entering the fleet during that year is calculated. New vehicle sales are estimated as the increase in total stock over the previous year plus the number of vehicles scrapped during the year. Vintages from new (zero years old) through to 20 years old are kept track of separately in the model, with vintage specific characteristics (such as litres/100 km) applied to any calculation involving their vehicle populations. Cars greater than 20 years of age are grouped together, with characteristics averaged over the numbers of such vehicles remaining in the fleet.

The number of vehicles of a particular vintage at the end of any year is calculated as the number at the end of the previous year minus the number scrapped during the year. The number of cars scrapped during any year is calculated by applying age-dependent scrappage rates to the vehicle stock numbers. Scrappage functions (that is, scrappage rates by age of vehicle) are calculated from the year to year differences of points on vintage survival curves (that is, curves plotting the proportion of vehicles of a particular vintage surviving to a particular age). Survival curves for Australian vehicles have been estimated using SMVU and MVC data (ABS 1995 and earlier, ABS 1993a and earlier).

As for vehicle ownership, a logistic formulation was chosen for vehicle survival, though with the opposite sign on the exponential, since the survival rate should approach zero (asymptotically) as time increases. The form of the equation used is:

$$S_i(T) = 1\ /\ (a + (1 - a)\ e^{bT})$$

where $S_i(T)$ refers to the proportion of cars of a particular vintage ($i$) surviving to an age of $T$ years, $a$ and $b$ are constants specific to each vintage.

The survival functions (grouped according to year of vehicle manufacture) fitted for the model, are:

Pre-1970 cars;

$S_{i \leq 1970}(T) = 1 \;/\; (0.9663 + 0.337\, e^{0.226\,T})$

1971 - 1979 cars;

$S_{1970<i<1980}(T) = 1 \;/\; (0.9803 + 0.0197\, e^{0.222\,T})$

Post-1980 cars;

$S_{i \geq 1980}(T) = 1 \;/\; (0.9926 + 0.0074\, e^{0.245\,T})$

The above equations were estimated by Iterative Non-linear Least Squares, with the R-squared being above 0.996 for all regressions. The latter half of the curve for post-1980 cars was obtained by requiring that the tail of the curve (for vehicles older than 35 years of age) be the same as that derived for pre-1970 cars.

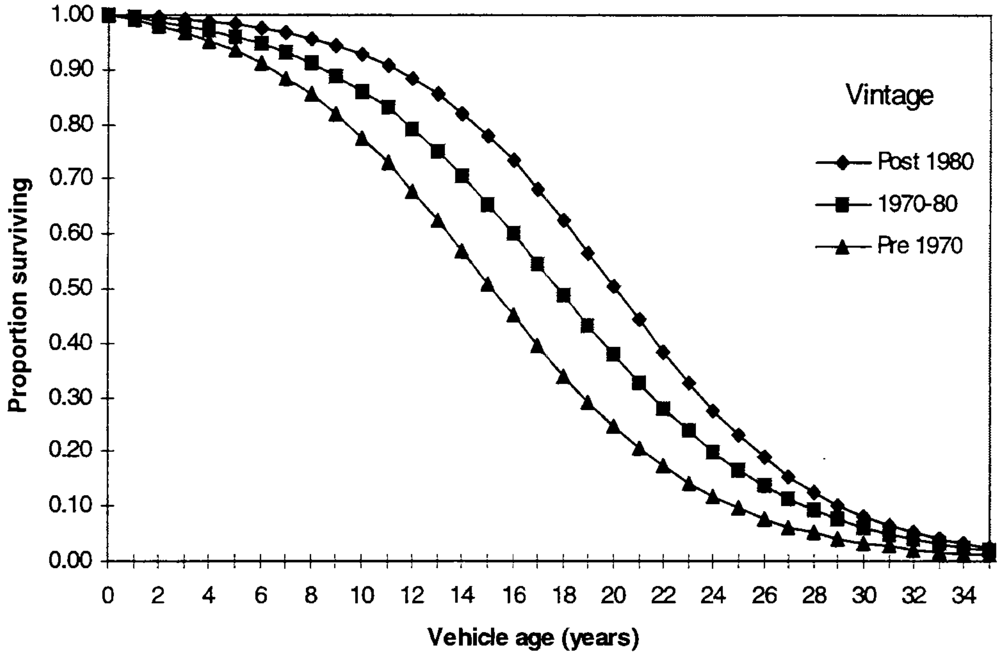
The model allows the further specification of a different curve for cars made in future years (which is set to the post-1980 curve as the base case). The survival functions and their associated scrappage functions are plotted in the figures 2.2 and 2.3, which show how current model cars tend to be on the road considerably longer than cars manufactured before the 1980s.

Economic factors can be incorporated into the survival functions $S_i(T)$ in the same fashion as for the car ownership function *MVPER*. However, the literature (Williams unpub., Thoresen & Wigan 1988, Walker 1968, Parks 1977, Greene & Chen 1981) suggests that such variables are generally not significant, with the age of the vehicle being the prime determinant of average scrappage rates. As with this study, Williams (unpub., p. 16) found that average car lifetimes lengthened significantly during the 1970s and 1980s, presumably due to 'the inherent vehicle technical durability' improving over time. For example, the proportion of cars manufactured in mid-1960s that survived to the age of 20 years was around 20 per cent, compared with around 40 per cent for the cars from the mid-1970s. Based on the fitted curves, it is expected that over half of cars with a post-1980 year of manufacture will survive to 20 years of age.

The base case projections have annual new vehicle sales at about 580 thousand cars per annum in 2015 (figure 2.4). Fleet composition by age of vehicle changes over the projection period such that the proportion of cars aged over 20 years increases significantly by 2015 (figure 2.5).

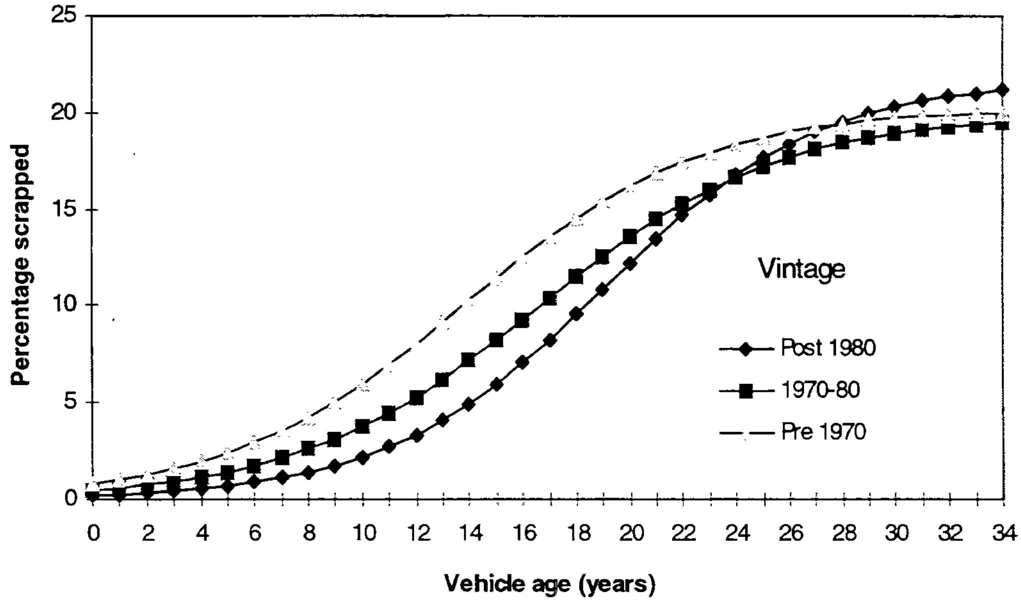
Inputs allowed to this part of the model include any variations to the base case scrappage rates and the year that such variations are to commence. The model responds by adjusting projected fleet fuel consumption (and emissions) depending on which portions of the fleet are affected.

FIGURE 2.2 SURVIVAL CURVES: PROPORTION OF INITIAL STOCK REMAINING, BY AGE OF VEHICLE FOR DIFFERENT VINTAGES



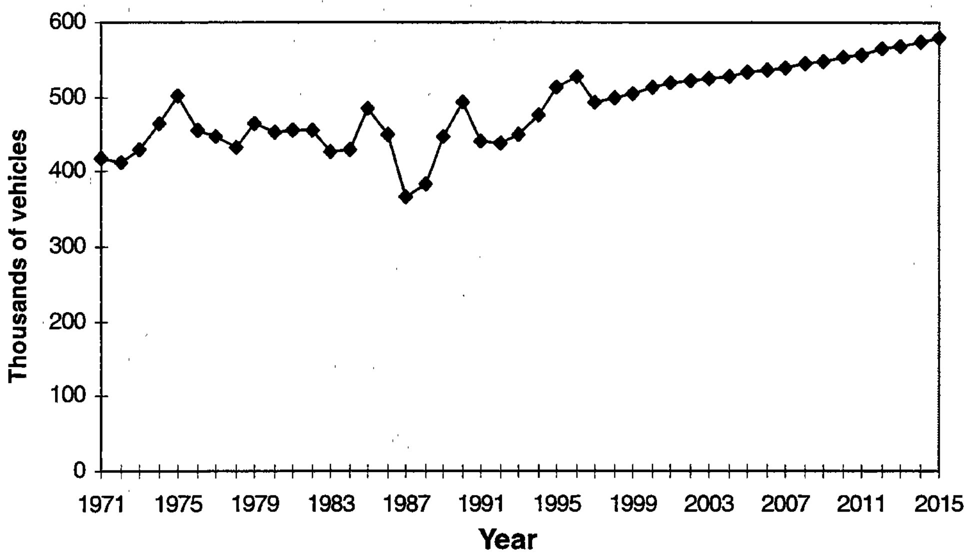

*Sources* BTCE estimates; BTCE (1995); ABS (1995 and earlier, 1994a and earlier, 1993a and earlier); CBCS (1973); Williams (unpub.).

FIGURE 2.3 SCRAPPAGE CURVES: PROPORTION OF REMAINING STOCK SCRAPPED, BY AGE OF VEHICLE FOR DIFFERENT VINTAGES



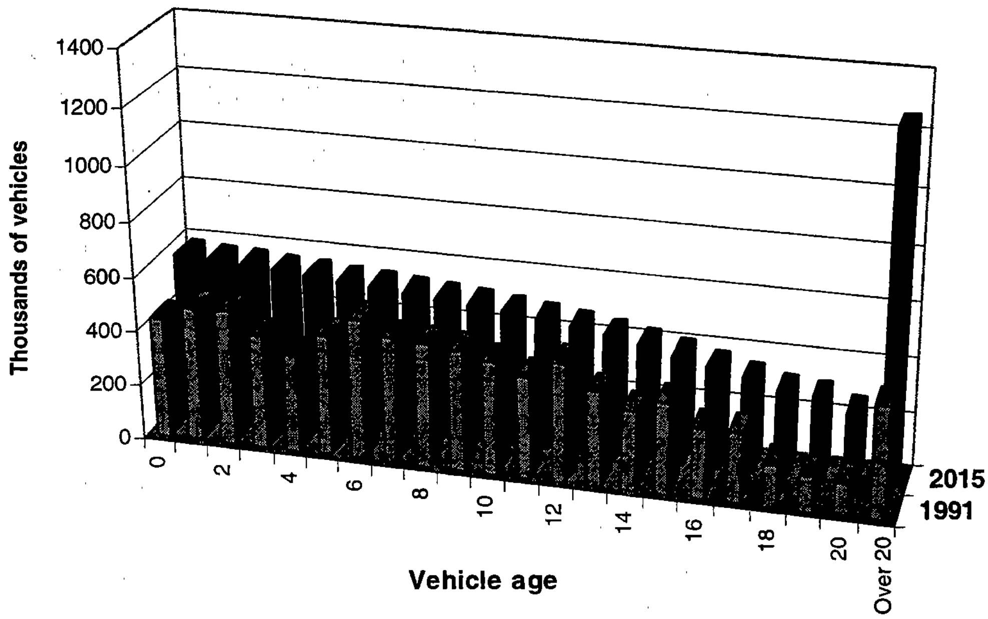

*Sources* BTCE estimates; BTCE (1995); ABS (1995 and earlier, 1994a and earlier, 1993a and earlier); CBCS (1973); Williams (unpub.).

FIGURE 2.4 BASE CASE NEW VEHICLE SALES, 1971–2015




*Sources* BTCE estimates; BTCE (1995); ABS (1994a and earlier).

FIGURE 2.5 COMPOSITION OF PASSENGER CAR FLEET BY AGE OF VEHICLE, 1991 AND 2015




*Sources* BTCE estimates; BTCE (1995); ABS (1995 and earlier, 1994a and earlier, 1993a and earlier).

**Population**

The Australian Bureau of Statistics (ABS) provides several scenarios which project the size of the Australian population. The 'A and B' scenario (ABS 1994a) is used for both the Report 88 model and CARMOD. It assumes medium levels of fertility 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 into the model by the user.

Multiplying the two components—projected population growth and projected vehicles per person—results in the projection of total vehicle numbers. The base case estimates the Australian fleet at 11 million cars by 2015.

**Vehicle utilisation**

Average vehicle kilometres travelled (VKT) per car has been assumed to remain constant at 15 500 kilometres per year; in keeping with the trend over the last couple of decades (figure 2.6).

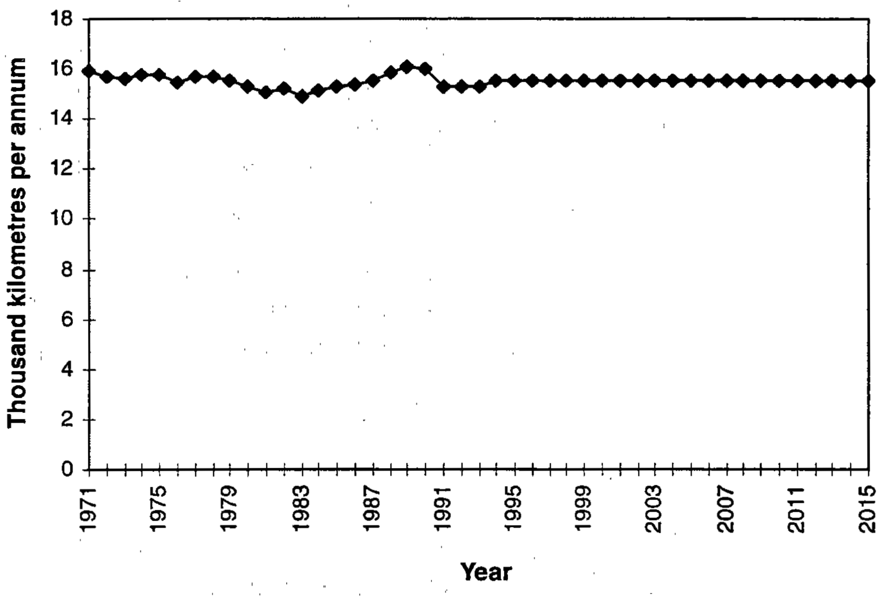
Several factors may influence the average distance a car is driven. On one hand, increasing incomes would tend to increase the demand for mobility, and therefore the utilisation of cars. Alternatively, traffic congestion in Australian cities is likely to increase over the next 20 years, as is the incidence of two and three car households, lowering the average utilisation per vehicle. The increasing average age of the Australian adult population (ABS 1994b) could also reduce average VKT in the future (Gallez 1994).

Since these effects appear to roughly counter-balance each other, fleet VKT per vehicle stays constant at of 15 500 km per year in the base case. In the model, average fleet VKT can be changed by the user to any particular value or function (for example, of fuel prices or income levels) 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 SMVU (ABS 1993a). The distribution set for the base case, which has a new vehicle travelling on average over twice as far in a year as a 20 year old vehicle, is given in table 2.2. To allow for cars being purchased throughout the course of a particular year, it is assumed in the model that average new car VKT *in that year* is half of their total annual VKT (that is, 12 250 km). An input to the model is how the distribution of VKT by age of vehicle changes over time (the base case default is constant at the 1991 distribution).

The base case projections have total passenger car travel increasing by 28 per cent between 1995 and 2015, to be 170.5 billion kilometres by 2015.

FIGURE 2.6 AVERAGE ANNUAL KILOMETRES TRAVELLED PER VEHICLE FOR AUSTRALIAN PASSENGER CAR FLEET




*Sources* BTCE estimates; BTCE (1995); ABS (1993a and earlier).

TABLE 2.2 AVERAGE ANNUAL VEHICLE UTILISATION BY AGE OF VEHICLE, 1991

| *Vehicle age (years)* | *Annual utilisation (kilometres)* |
|---|---|
| 0 | 24500 |
| 1 | 22700 |
| 2 | 20075 |
| 3 | 19250 |
| 4 | 18425 |
| 5 | 17600 |
| 6 | 17000 |
| 7 | 16400 |
| 8 | 15800 |
| 9 | 15200 |
| 10 | 14740 |
| 11 | 14280 |
| 12 | 13820 |
| 13 | 13360 |
| 14 | 12900 |
| 15 | 12250 |
| 16 | 11600 |
| 17 | 10950 |
| 18 | 10500 |
| 19 | 10300 |
| 20 | 10000 |
| Over 20 | 9000 |

*Sources* BTCE estimates; BTCE (1995); ABS (1993a and earlier).

**Average fuel intensity of the car fleet**

The average fuel intensity (litres/100 km) of the cars in the Australian fleet is a crucial variable in forecasting fuel consumption. To forecast fuel intensity adequately, it is necessary to adopt an approach like that of the BTCE model; 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/100 km to 8.06 litres/100 km in 2004-05. This decline is the base case projection of a study done for the Federal Office of Road Safety (FORS) on the potential to improve car fuel economy (NELA 1991, p. 49), and is based on car industry product plans adjusted to account for the introduction of anticipated new vehicle emissions and safety standards by the end of the century. Fuel intensity is assumed to fall further to 6.5 litres/100 km (a maximum technology scenario for 2004-05) by 2014-15 (NELA 1991, p. 46). That is, the BTCE assumes 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.

The above rated fuel intensities of new cars relate to trends in National Average Fuel Consumption (NAFC), which is 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 cause 'real world' fuel consumption to be around 20 per cent higher than for the dynamometer tests used to estimate NAFC. BTCE CARMOD includes conversion factors for scaling up cycle test values to better reflect on-road driving conditions.

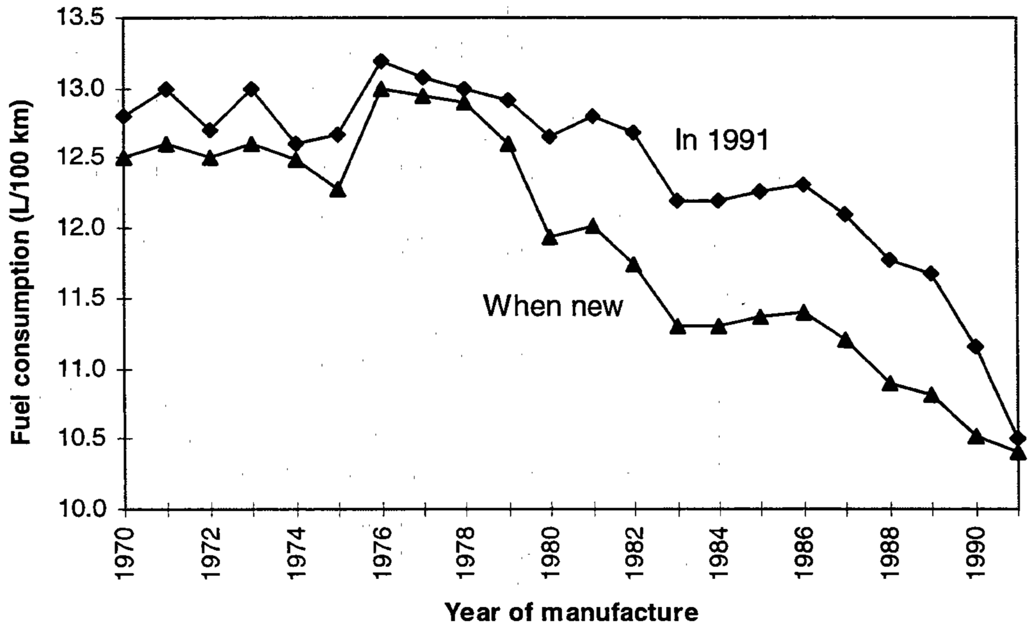
In the model, the current difference between NAFC and on-road fuel consumption is set to 18 per cent (based on ABS 1993a and earlier, Watson 1992, FORS 1991). Since improvements in engine management systems are allowing the on-road fuel consumption of new vehicles to be closer to cycle test results (Watson 1992), the base case assumes that the difference declines to 12 per cent by 2015. The base case thus assumes that current on-road average fuel intensity of 10.4 litres/100 km will decline to 7.3 litres/100 km by 2015. Alternative scaling factors for the gap between tested and on-road fuel consumption can be entered by the model user.

### *Deterioration*

Once a vehicle has entered the fleet, its fuel efficiency typically decreases as the vehicle ages, especially if the vehicle is not properly maintained. The pattern of how average fuel consumption for a vintage changes over time appears to consist of two trends: deterioration with age of each vehicle in the vintage, and the eventual scrappage of the less efficient members of the vintage. For each vehicle of a vintage, deterioration is assumed to cause fuel intensity to increase by about 3 per cent per annum, until it reaches a limit of 20 per cent greater than when new and remains constant thereafter (based on ABS 1993a and earlier, FORS 1995, Waters 1992). 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 (based on ABS 1993a and earlier). The model incorporates a vintage aging factor which is the result of combining these two opposing trends.

The default (base case) aging 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 (figure 2.7) when values of fuel intensity by year of manufacture in 1991 are plotted against the estimated litres/100km when new for each vintage. The vintage aging factor can be varied by the model user to suit the assumed scenario.

FIGURE 2.7 FUEL INTENSITY WHEN NEW VERSUS FUEL INTENSITY IN 1991, BY YEAR OF MANUFACTURE




*Sources* BTCE estimates; BTCE (1995); ABS (1993a and earlier); NELA (1991); Watson (1992).

### *Congestion*

The level of traffic congestion in major Australian cities is likely to increase considerably over the next 20 years. The base case projections have total passenger vehicle travel increasing by around 30 per cent by 2015. The consequent increases in urban congestion will probably result in higher fuel consumption and emission rates.

To allow the inclusion of congestion effects, total vehicle kilometres travelled are divided in the model between urban and non-urban travel. The base case has the proportion of total kilometres due to urban travel remaining constant (through to 2015) at the current level of 70 per cent (ABS 1993a). The proportional split between urban and non-urban travel has not changed appreciably over the last 10 years (ABS 1993a and earlier, Apelbaum 1993).

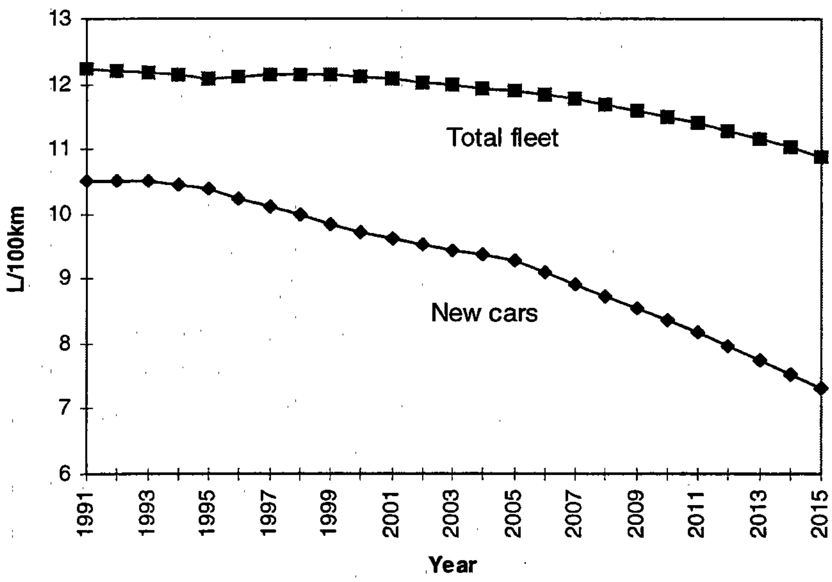
Based on analysis in the literature of the dependence of urban fuel consumption rates on average travel speed and traffic congestion levels, increases of 30 per cent in kilometres travelled could increase the fuel intensity of urban vehicles by 5 to 10 per cent (Poldy & Evill 1995, Watson 1995, Waters 1992). Taking into account the trends in utilisation of other vehicle types implies even higher congestion levels are possible. The BTCE base case projections for road freight (BTCE 1995) show strong expected growth in freight vehicle use, particularly for light commercial vehicles. The base case projections of Report 88 (BTCE 1995) 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 is assumed that traffic levels under congested conditions increase by 30 per cent (rather than the full 50 per cent). It is assumed in the base case 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 above effects (technological improvement, deterioration and congestion) gives a base case projection of fleet average fuel intensity declining from 12.1 litres/100km in 1995 to 10.9 litres/100km by 2015, as industry efficiency programs reduce (on-road) new car fuel intensities from 10.4 to 7.3 litres/100 km (figure 2.8).

The effects on average fuel consumption of different policy scenarios (dealing with the vehicle fleet) can be simulated by the model.

If a scenario involves extra scrappage of a particular vintage the model allows for the subsequent variation in average fleet fuel consumption. The adjustment is accomplished even if particularly inefficient vehicles are assumed to be targeted, the required inputs being the percentage that the 'gross polluters' fuel consumption is greater than the average for the vintage they belong to, and what proportion of the vintage they comprise.

FIGURE 2.8 PROJECTED FLEET AND NEW VEHICLE FUEL INTENSITY




*Sources* BTCE estimates; BTCE (1995); ABS (1993a and earlier); NELA (1991); Watson (1992).

A similar input table allows analysis of the aggregate effects of vehicle inspection and maintenance campaigns. Either independent of the scrappage assumptions above or integrated with them, inputs to this section of the model consist of the percentage of each vintage that would be affected by vehicle testing measures, the percentage that a single service on those vehicles would reduce fuel consumption, and the upper limit on how much the fuel consumption of that vintage could be improved by servicing.

## Total fuel consumption

The vintage specific figures for fuel intensity (litres/100km) and average VKT permit estimates to be made of total fuel consumption by the Australian passenger car fleet for any particular year.

The base case has total fuel consumption by cars projected to increase by 15 per cent, from 549 petajoules ($10^9$ joules, see appendix I for energy conversion factors) in 1995 to 634 petajoules in 2015.

The total is divided into fuel types based on current fuel splits and extrapolated penetration levels of alternative fuels. The base case assumes that by 2015, liquefied petroleum gas (LPG) accounts for 7 per cent of total energy consumption by cars, natural gas 2 per cent, automotive diesel 3.5 per cent, and other alternatives are negligible.

Different assumed penetration rates can be readily entered into the model.

**Emissions**

Greenhouse gas emissions arising directly from road vehicles consist of the gaseous products of engine fuel combustion (*exhaust emissions*) and gas leakage from vehicles (*fugitive emissions*), essentially comprising:

- $CO_2$ emissions due to the oxidation of fuel carbon content during fuel combustion;
- $CH_4$, $N_2O$, $NO_x$, CO and NMVOC emissions resulting from incomplete fuel combustion, reactions between air and fuel constituents during fuel combustion and post-combustion reactions; and
- fugitive emissions of fluorocarbons, due to vehicle air-conditioner refrigerant release, and of hydrocarbons (HCs), due to fuel evaporation.

The bulk of NMVOC emissions from petrol vehicles consist of hydrocarbons (around 97 per cent).

Fluorocarbon emissions from Australian passenger vehicles are not dealt with here. Estimates of fluorocarbon emissions from the transport sector are provided in Report 88 (BTCE 1995, p. 5), along with average leakage rates from vehicle air-conditioners (BTCE 1995, pp. 193-194). The model estimates emissions of all the other species mentioned above, on a year by year basis.

The accurate estimation of mobile source emissions is complex since 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.* Emission rates in the model are expressed as grams of gas emitted per megajoule of energy used (g/MJ) for $CO_2$ emissions and grams emitted per vehicle kilometre travelled (g/km) for non-$CO_2$ emissions.

The model estimation of $CO_2$ emissions is 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 primary 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 account of in the default GWPs.

Emissions are calculated in the model on a very disaggregated basis, and allow inputs for changes due to cold versus hot start ratios, greater scrappage 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*

The model has separate emission rates for each pollutant, and these rates are adjusted depending upon the driving stage and the age of the vehicle (see appendix II).

Passenger car emission rates depend principally upon the type of emissions control technology fitted to the vehicle. Essentially, the model includes separate emission rates for the following categories of vehicles (split according to year of manufacture):

- post-1985
- 1981–1985
- 1976–1980
- pre-1976.

The pre-1976 group of cars essentially has no emissions control, the 1976–80 and 1981–85 groups use a variety of non-catalytic control (such as exhaust gas recirculation), and the post-1985 group uses catalytic control. Around 80 per cent of post-1985 petrol cars are fitted with 3-way catalytic converters, and most of the remainder are fitted with oxidation (or 2-way) catalysts.

In order to make projections, it is necessary to consider how the emissions performance of cars manufactured in future years will compare with current models. In Australia, emissions standards for new cars were last set by the Federal Government in 1986, with the introduction of unleaded petrol and catalytic converters. Emissions standards are expected to be made more stringent in 1997 (table 2.3). The base case 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 the model. 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.

TABLE 2.3 EMISSION STANDARDS FOR NEW PASSENGER CARS

| *Year of introduction* | *Emission standard (g/km)* | | |
|---|---|---|---|
| | *CO* | *HC* | *$NO_x$* |
| *Current standard* | | | |
| 1986 | 9.3 | 0.93 | 1.93 |
| *Proposed* | | | |
| 1997 | 2.1 | 0.26 | 0.63 |

*Source* FORS (1993).

As for new vehicle fuel consumption rates, vehicle emission rates are generally derived from dynamometer tests using specified drive cycles. The Australian Design Rules (ADRs) for motor vehicles specify compliance with emission standards under two drive cycles: one for ADR 37 (for vehicles manufactured after 1985), and another for ADR 27A (for vehicles manufactured prior to 1985). Since many on-road driving conditions are not adequately simulated by test drive cycles, the emissions rates derived tend to underestimate urban emission levels. As for the fuel intensity methodology, BTCE CARMOD includes conversion factors for scaling up cycle test values to better reflect on-road driving conditions.

In the model, the average emission rates are based on tests over the ADR 27A drive cycle, scaled according to whether the travel is urban or non-urban. Using Watson's (unpub.) analysis of emissions over drive cycles more representative of Australian urban driving, scaling factors were derived for the conversion of ADR 27A emission rates into on-road estimates. Factors for urban and non-urban driving (based on emissions rates from Carnovale et al. 1991, FORS 1995, BTCE 1995, Watson unpub., and EPA NSW 1995) are given in table 2.4, 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.

European tests (Lenaers & Vlieger 1995) have been conducted under actual city traffic conditions, using on-board emission measurement systems, to estimate the effects of driving behaviour on fuel consumption and emission rates. Lenaers and Vlieger (1995, p. 12) present results that show aggressive driving (sudden acceleration and heavy braking) to have 39 per cent higher fuel consumption and over five times the level of noxious emissions as calm driving (avoiding sudden acceleration).

TABLE 2.4 CONVERSION FACTORS FOR DRIVE CYCLE TO ON-ROAD EMISSION RATES

| Sector | Vehicle type | Emissions | | |
|---|---|---|---|---|
| | | 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 (unpub.), FORS (1995), Carnovale et al. (1991), BTCE (1995), EPA NSW (1995).

Studies show that most new vehicles have better emission performance than the current emission standards (Carnovale et al. 1991, SPCC 1989). Therefore, the base case assumption of new cars between 1997 and 2015 simply meeting the proposed emission standards could be viewed as conservative. However, the proposed standards are probably reasonable as a base case level for future emissions over an ADR 27A drive cycle since 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 intensity, emission rates generally increase as a vehicle ages, even with newer emission control technology (particularly since catalytic converter efficiency decreases over time). Emission performance deterioration can be due to gradual wearing of vehicle components, poor levels of maintenance, oxygen sensor failure, tampering with emission control equipment and engine modifications.

Emission rates (given in g/km) in the model therefore incorporate deterioration factors (given 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 2.5.

TABLE 2.5 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 (unpub.), FORS (1995), Carnovale et al. (1991), EPA NSW (1995), Waters (1992).

### *Congestion*

To allow for future changes in average driving patterns, separate emission rates (see appendix II) are included in the model 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 NSW 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 base case 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.

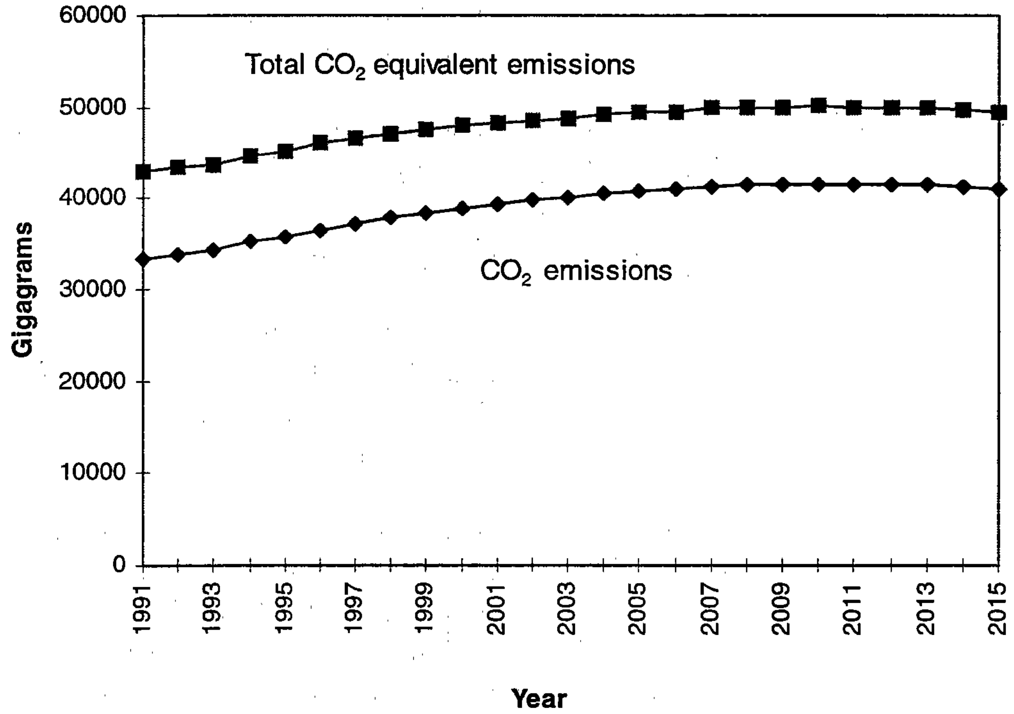
The default (base case) proportions can readily be varied in the model.

## BASE CASE EMISSION PROJECTIONS

Running the model using the default assumptions detailed in the above sections, results in a base case projection of $CO_2$ emissions from the car fleet in 2015 of about 15 per cent above the 1995 level (figure 2.9). 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, $NO_x$ decline slightly (around 5 per cent), and $N_2O$ emissions approximately double by 2015 (see appendix II for detailed numerical tables) (Figure 2.10).

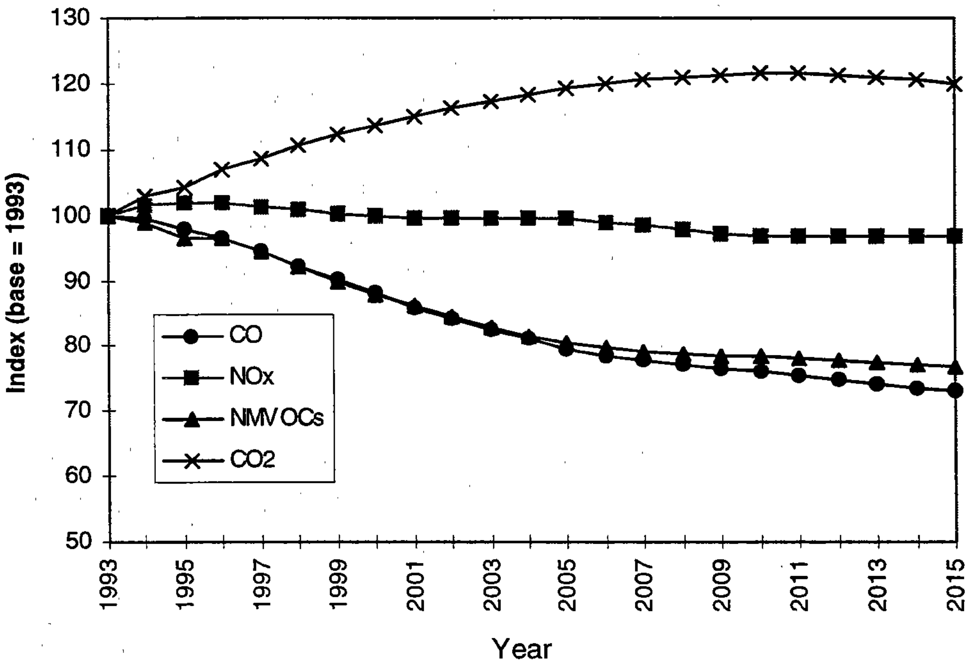
Non-$CO_2$ greenhouse emissions vary in their GWPs relative to an equal mass of $CO_2$. The default GWP values in the model (see appendix I) are $CH_4$ 24.5, $N_2O$ 320, $NO_x$ 8, CO 1, and NMVOCs 8. Total $CO_2$ equivalent emissions from cars are therefore projected to increase to be nearly 50 million tonnes (9.3 per cent higher than 1995 levels) by 2015.

FIGURE 2.9 BASE CASE PROJECTIONS OF TOTAL CAR FLEET EMISSIONS TO 2015




*Sources* BTCE estimates, BTCE (1995).

FIGURE 2.10 INDICES OF PROJECTED EMISSION LEVELS, 1993–2015




*Sources* BTCE estimates, BTCE (1995).

# CHAPTER 3 ADJUSTABLE MODEL PARAMETERS FOR POLICY SIMULATIONS

The fleet dynamics model developed by the BTCE can simulate the implementation of possible emission abatement measures. Although any particular scenario can be realised by editing the underlying data tables of CARMOD, most of the model variables can also be adjusted by direct user input to a table of key values. The model incorporates a set of parameter values which the model user can adjust to suit different policy scenarios. This chapter lists the adjustable parameters included in the model and their default values.

To allow simulation of the effects of different policy scenarios on passenger car emissions, the following inputs are allowed for in the model:

- further improvements in fuel efficiency or emission control technology for future new cars;
- changes to the trends in motor vehicle ownership, vehicle scrappage rates or average vehicle utilisation;
- changing congestion levels and driving patterns for urban traffic;
- the rate of deterioration in fuel efficiency and emission performance with vehicle age;
- a given percentage of new cars to be fitted with warm-up converters to reduce cold start emissions;
- catalyst replacement of a given percentage of a vintage after a given number of years;
- the proportion of vehicles that are gross polluters, their percentage contribution to fleet emission levels, and what proportion of them can be removed from the fleet;
- the reductions in the emission of each gas after vehicle servicing, the percentage of the fleet that would be affected by a vehicle inspection campaign, and the frequency of the required services.

For a scenario, any proposed measures can have their year of implementation specified and the model will then track how vintage specific effects move through the car fleet over time.

**Numbers in bold in the following sections denote values that the user can change in the model's input table and have the model recalculate the ensuing projections.**

## SCENARIO DEVELOPMENT

### Motor vehicle ownership

Future levels of cars per thousand population (*MVPER*) can be set year-by-year to any level required. Alternatively, the parameters $k$, $a$ and $b$ of the logistic function

$$MVPER = k \,/\, (1 + ae^{-bt})$$

can be altered (in the input table) from the default values:

$k$ = **516**

$a$ = **7.65**

$b$ = **0.0896**

### Scrappage rates

From the fitted survival curves, using the logistic form

$$S_i(T) = 1 \,/\, (a + (1 - a)\, e^{bT})$$

where $S_i(T)$ refers to the proportion of cars of a vintage $i$ surviving to an age of $T$ years, scrappage rates $R_i(T)$ are calculated by:

$$R_i(T) = (S_i(T) - S_i(T+1)) \,/\, S_i(T) \times 100$$

where $R_i(T)$ is the percentage of vehicles of vintage $i$ (remaining to an age of $T$ years) scrapped over the following year.

The scrappage rates in the model (given in table 3.1) can be edited directly in the model's lookup tables or controlled by changing parameters in the input table.

Changes in vehicle stocks are then calculated by

$$Stock_i(Y+1) = Stock_i(Y)\,(1 - R_i(Y - i) \,/\, 100)$$

where $Stock_i(Y)$ is the number of vehicles of vintage $i$ remaining in year $Y$.

Vintages of over 20 years old are aggregated and their characteristics (for example, fuel efficiency) are averaged over the remaining vehicles. Scrappage rates for the these older vehicles depend on a summation over the tails of the survival curves (figure 2.2).

TABLE 3.1 SCRAPPAGE RATES FOR VINTAGE GROUPS

| *Vehicle age* | *Scrappage rates* | *($R_i(T)^a$ (per cent))* | |
|---|---|---|---|
| *T (years)* | *Pre-1970* | *1971–1979* | *Post-1980* |
| 0 | 0.8 | 0.5 | 0.2 |
| 1 | 1.1 | 0.6 | 0.3 |
| 2 | 1.3 | 0.7 | 0.3 |
| 3 | 1.6 | 0.9 | 0.4 |
| 4 | 2.0 | 1.1 | 0.5 |
| 5 | 2.4 | 1.4 | 0.7 |
| 6 | 2.9 | 1.7 | 0.9 |
| 7 | 3.5 | 2.1 | 1.1 |
| 8 | 4.3 | 2.6 | 1.4 |
| 9 | 5.1 | 3.1 | 1.7 |
| 10 | 6.0 | 3.7 | 2.2 |
| 11 | 7.0 | 4.5 | 2.7 |
| 12 | 8.0 | 5.3 | 3.3 |
| 13 | 9.1 | 6.2 | 4.1 |
| 14 | 10.3 | 7.2 | 4.9 |
| 15 | 11.4 | 8.2 | 5.9 |
| 16 | 12.5 | 9.3 | 7.0 |
| 17 | 13.6 | 10.4 | 8.3 |
| 18 | 14.5 | 11.5 | 9.5 |
| 19 | 15.4 | 12.5 | 10.9 |
| 20 | 16.2 | 13.5 | 12.2 |

a. $R_i(T)$ is the percentage of vehicles of vintage *i* (remaining to an age of *T* years) scrapped over the following year.

*Sources* BTCE estimates; ABS (1995 and earlier, 1994a and earlier, 1993a and earlier); CBCS (1973); Williams (unpub.).

Such group scrappage rates are approximated by

$$R20_{ij}(Y) = R20_{ij}(Y^*)\,(1 + n/100)^{Y-Y^*}$$

where

$R20_{ij}(Y)$ is the percentage of vehicles scrapped in year $Y$ that are over 20 years of age and were manufactured between the years $i$ and $j$;

$Y^*$ is the year such aggregation commences for the different vintage groups, that is, 1991 for the pre-1970 vintage group, 1992 for $i$ = 1971 to $j$ = 1979, and 2001 for post-1980 cars; and

$n$ is the percentage that the group scrappage rate increases per annum.

Both $R20_{ij}(Y^*)$ and $n$ are adjustable parameters in the input table, the default values of which are given in table 3.2.

Policies whose effects include the accelerated scrappage of vehicles can be simulated by two other parameters in the input table—an $m$ per cent increase in the scrappage rates, taking effect from year $YPS$:

$$RPS_i(T) = R_i(T)\,(1 + m/100) \qquad \text{if } Y \geq YPS$$

$$RPS_i(T) = R_i(T) \qquad \text{if } Y < YPS$$

where $RPS_i(T)$ refers to the scrappage rates of the policy simulation.

For the base case projections, $m$ is set to zero.

TABLE 3.2 SCRAPPAGE RATE PARAMETERS

*per cent*

| *Vintage group* | $R20_{\pi}(Y^*)$ | *n* | *m* |
|---|---|---|---|
| Pre-1970 | **18.0** | **0.5** | **0** |
| 1971–1979 | **14.5** | **1.0** | **0** |
| Post-1980 | **13.5** | **1.5** | **0** |

*Sources* BTCE estimates, ABS (1995 and earlier, 1994a and earlier, 1993a and earlier), CBCS (1973), Williams (unpub.).

After any variations to the base case scrappage rates are made, the model re-estimates fleet fuel consumption and emissions. The dependence of average fuel consumption and emission rates on the accelerated scrappage of portions of the fleet can be controlled in the model by a further set of parameters in the input table.

If the scenario presumes that the extra scrappage is targeted at less efficient vehicles (so called 'gross polluters'), a parameter ($k$) can be used to specify how faulty such vehicles are. If the gross polluters in vintage $i$ have $k$ per cent worse fuel consumption than the vintage average, then the fuel intensity after a year $Y$ with $m$ per cent extra scrappage is (neglecting vehicle deterioration with age):

$$FI_i(Y+1) = FI_i(Y)\,(1 - (1+k/100)m/100)/(1 - m/100)$$

where the fuel intensity of vintage $i$ in year $Y$, $FI_i(Y)$, is constrained so as to never drop below some lower bound. Another input parameter ($LB1$) specifies the maximum advantage possible by increasing scrappage. The model imposes the following condition over the projection period:

$$FI_i(Y) \geq (1 - LB1/100)\,FI_i(i)$$

that is, the average fuel intensity of vintage $i$ cannot be decreased further than $LB1$ per cent below the average for the vintage when new. The model default values (based on FORS 1995, ABS 1993a and earlier) are $k$ = **20** and $LB1$ = **5**.

An equivalent process is performed by the model for emissions of CO, NMVOCs and $NO_x$. The model adjusts the average emission rates for the different vintages depending on how much extra scrappage occurs in each vintage under the policy scenario. The model default assumption is that the worst 10 per cent of vehicles account for around 30 per cent of noxious emissions from the car fleet (based on FORS 1995, ABS 1993a and earlier, SPCC 1989 and earlier). That is, the model assigns (default) gross polluter emission rates that are three times higher than the respective vintage averages ($k$ = **200**). It is also assumed that the maximum advantage possible by increasing scrappage is to reduce average noxious emission rates to the level when new for the each vintage ($LB1$ = **0**).

**Vehicle utilisation**

Although the fleet value for average travel per car is set to a particular constant in the base case ($VKT_{fleet}$ = **15 500** km per year), any value or series of values can be fed into the model. An input parameter allows for either steadily increasing or steadily decreasing average utilisation over the forecast period:

$$VKT_{fleet}(Y+1) = (1 + u/100)\ VKT_{fleet}(Y)$$

where $u$ is the change per annum in projected vehicle kilometres travelled.

Total kilometres travelled by the car fleet in a year, $T(Y)$, are then given by

$$T(Y) = VKT_{fleet}(Y)\ (\ \Sigma_i\ Stock_i(Y)\ )$$

When dividing total distance travelled by the fleet between the vintages, the model uses a distribution by age of vehicle (based on the values $VKT_i(Y)$ given in table 2.2). The values of average annual utilisation for each vintage change slightly from year to year, so as to maintain the fleet average value for each year (as set above). The overall shape of the distribution does not change significantly from year to year. For any year $Y$, the slight difference between $T(Y)$ and total travel calculated using the values of table 2.2, $T(Y)^*$ say, is apportioned evenly between the vintages, where

$$T(Y)^* = \Sigma_i\ (VKT_i(Y)\ Stock_i(Y))$$

Distributions that differ from the base case values of table 2.2 can be entered by the user.

For the base case, the distribution is such that utilisation of new vehicles (24 500 km per year) and of vehicles older than 20 years ($VKT_{i<Y-20}(Y)$ = **9000** km) are constant over the projection period. On average, new cars bought throughout the year are in-service for about half of the year, so the model sets utilisation during year $Y$ of vintage $Y$ cars to half the annual value ($VKT_Y(Y)$ = **12 250** km). Input parameters ($v1$, $v21$) allow the user to alter the endpoints of the distribution:

$$VKT_Y(Y)^{PS} = v1(Y)\ VKT_Y(Y)$$

$$VKT_{i<Y-20}(Y)^{PS} = v21(Y)\ VKT_{i<Y-20}(Y)$$

where the PS superscript denotes that the VKT values are for some policy scenario. For the base case, $v1$ and $v21$ are set to **1** for all years.

The percentage of total kilometres due to urban travel can also be specified. The base case has the urban share at a constant **70** per cent of $T(Y)$ over the projection period.

### New car fuel intensity

The input tables allow new car fuel intensity (NAFC) and scaling factors for on-road driving conditions to be specified at five-yearly intervals (as shown for the base case in table 3.3). Values for intermediate years are then interpolated.

TABLE 3.3 PROJECTED NEW CAR FUEL INTENSITY

| *Year (Y)* | *NAFC (litres/100km)* | *Scaling factor* | *On-road fuel intensity ($FI_Y(Y)$) (litres/100km)* |
|---|---|---|---|
| 1995 | **8.80** | **1.18** | 10.38 |
| 2000 | **8.45** | **1.15** | 9.71 |
| 2005 | **8.06** | **1.15** | 9.27 |
| 2010 | **7.48** | **1.12** | 8.38 |
| 2015 | **6.54** | **1.12** | 7.33 |

*Sources* NELA (1991), ABS (1993a), Watson (1992), FORS (1991), BTCE estimates.

### Deterioration of fuel intensity

The aging factor for the average fuel intensity of a vintage is the aggregate effect of each vehicle deteriorating (given by parameter $r1$) and the tendency for the least efficient members of a vintage to be scrapped first (given by parameter $r2$):

$$FI_i(Y+1) = FI_i(Y)\ (1 + r1)\ (1 + r2)$$

### Urban fuel intensity

The model also allows the specification of how future levels of urban congestion will increase average fuel intensities of vehicles. The base case input is that by 2015, increased congestion will cause an additional **10** per cent fuel consumption by urban cars (that is, 10 per cent above the level expected if congestion does not increase). It is assumed that this add-on is approached steadily over the period.

TABLE 3.4 DETERIORATION OF FUEL INTENSITY WITH AGE

| *Vehicle age* | *Aggregate ((1 + r1) (1 + r2))* | *Vehicle deterioration (r1)* | *Scrappage of inefficient vehicles (r2)* |
|---|---|---|---|
| 0 | 1.00 | **0** | **0** |
| 1 | 1.03 | **0.03** | **0** |
| 2 | 1.06 | **0.06** | **0** |
| 3 | 1.09 | **0.09** | **0** |
| 4 | 1.12 | **0.12** | **0** |
| 5 | 1.14 | **0.14** | **0** |
| 6 | 1.16 | **0.16** | **0** |
| 7 | 1.18 | **0.18** | **0** |
| 8 | 1.19 | **0.19** | **0** |
| 9 | 1.20 | **0.20** | **0** |
| 10 | 1.20 | **0.20** | **0** |
| 11 | 1.20 | **0.20** | **0** |
| 12 | 1.19 | **0.20** | **-0.01** |
| 13 | 1.18 | **0.20** | **-0.02** |
| 14 | 1.16 | **0.20** | **-0.03** |
| 15 | 1.15 | **0.20** | **-0.04** |
| 16 | 1.14 | **0.20** | **-0.05** |
| 17 | 1.13 | **0.20** | **-0.06** |
| 18 | 1.12 | **0.20** | **-0.07** |
| 19 | 1.10 | **0.20** | **-0.08** |
| 20 | 1.10 | **0.20** | **-0.08** |
| Over 20 | 1.10 | **0.20** | **-0.08** |

*Sources* ABS (1993a and earlier), FORS (1995), Waters (1992), BTCE estimates.

### Vehicle servicing

As for scenarios dealing with accelerated vehicle scrappage, input parameters allow the analysis of vehicle servicing. If a parameter *s1* denotes the percentage that a single service reduces the fuel intensity of an average vehicle, and another *s2* denotes the percentage of vehicles to be serviced each year under the scenario, then

$$FI_i(Y+1) = FI_i(Y)\ (1 - (s1/100)(s2/100))$$

As with increasing scrappage, the fuel intensity of vintage *i* in year *Y*, $FI_i(Y)$, is constrained so as to never drop below a lower bound:

$$FI_i(Y) \geq (1 + LB2/100)\ FI_i(i)$$

That is, the average fuel intensity of vintage *i* cannot be decreased further than *LB2* per cent above the average for the vintage when new. The model default values are *s1* = **3** and *LB2* = **5** (based on Waters 1992, FORS 1995, ABS 1993a and earlier).

For servicing scenarios, an equivalent process is performed for exhaust emissions of CO, NMVOCs and $NO_x$. The model default assumptions for emission improvements from vehicle servicing are that CO and NMVOC emissions are reduced by **30** per cent, while $NO_x$ emissions are not reduced for pre-1986 cars and reduced by **10** per cent for post-1986 cars (based on

Waters 1992, SPCC 1989 and earlier). These values refer to gains possible by servicing vehicles not in compliance with the emission standards. It is assumed that **30** per cent of the post-1986 vehicle fleet and **50** per cent for pre-1986 cars have emission rates above the standards. It is also assumed that the maximum advantage possible from vehicle servicing is to reduce average noxious emission rates for each vintage to around 10 per cent above when new:

$$FI_i(Y) \geq (1 + LB3/100)\ FI_i(i)$$

for $LB3$ = **10**.

### Emission rates

The model user can enter any required set of values for emission rates of future new cars (in the model lookup tables). Parameters in the input table allow a trend decrease in projected average emission output from new cars to be specified.

The conversion factors for drive cycle to on-road emission rates, given in table 2.4, are assumed in the base case to remain constant over the projection period. The model allows these factors to be altered over time.

Similarly, emission rate deterioration factors (default values given in table 2.5) can be altered to suit the scenario.

The model also allows for changes in average driving patterns, the proportions of total travel time due to cold start driving, stable driving conditions and driving on congested or minor roads.

As well as exhaust emission rates, evaporative emission rates can be varied over time. Evaporative HC emissions occur from hot soak losses (evaporation from the fuel system at the end of each trip), diurnal losses (resulting from fuel vapours being expelled from petrol tanks due to ambient temperature rises), running losses (vaporative emissions released during engine operation) and crankcase ventilation (in early model vehicles). The base case assumes that running losses will remain constant at **1** g/km to 2015. It is also assumed that the aggregate emission rate for other evaporative losses will approximately halve after the new emission standards come into force in 1997 (going from an average of **0.33** g/km for pre-1997 catalytically controlled cars to **0.16** g/km for post-1997 vehicles).

### Catalytic converters

The model includes a parameter to allow for new cars after a specified date to be fitted with warm-up converters to reduce cold start emissions. The model input is the percentage of new cars each year (after the implementation date) that have catalyst heaters fitted. The model then recalculates emissions levels, assuming that the noxious emission rates for such new cars are the same during cold start driving as for stable conditions.

Another input parameter allows for periodic catalyst replacement. On average, after about eight years of use, catalytic converter efficiency is severely degraded and the catalyst needs to be replaced. However, replacement for in-service vehicles is currently negligible (the base case assumes 1 per cent of failed catalysts are replaced). If a scenario assumes a policy of mandatory catalyst replacement, the model inputs are the percentage of vehicles affected and the frequency replacements are required.

**Other parameters**

The penetration rates (by 2015) of alternative transport fuels in car fleet energy use can be altered to suit the scenario. Different energy densities and emission factors for alternative fuels can also be specified (default values given in appendix I).

The global warming potentials (GWPs) for non-$CO_2$ emissions can also be set to whatever values the user requires. GWP values used in this working paper (given in appendix I) are identical to those used in BTCE Report 88 (BTCE 1995, p. 144).

## ...AT A GLANCE

## ACCELERATED INTRODUCTION OF FUEL SAVING TECHNOLOGY

Considerable scope exists for the accelerated introduction of more fuel efficient cars. As the new fuel efficient cars penetrate the fleet, emissions of greenhouse gases will be progressively reduced.

## KEY FEATURES

- 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 1996. It is also assumed that a doubling in fuel efficiency incurs an increase of 10 per cent in vehicle prices.
- Large reductions in greenhouse gas emissions are achievable, especially over the longer term (20 years).
- Reductions could be achieved at comparatively low cost.
- Initially, reductions can be achieved at negative costs. That is, for moderate fuel efficiency standards for new cars, the policy can be described as one of 'no regrets'.

FIGURE 4.1 FUEL SAVING TECHNOLOGY: MARGINAL COSTS FOR 2000

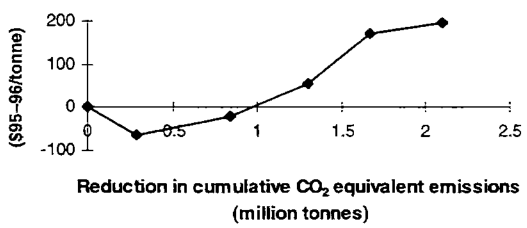



FIGURE 4.2 FUEL SAVING TECHNOLOGY: MARGINAL COSTS FOR 2005

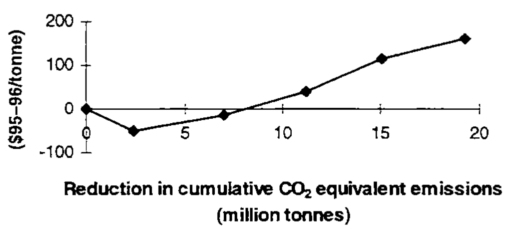



FIGURE 4.3 FUEL SAVING TECHNOLOGY: MARGINAL COSTS FOR 2010

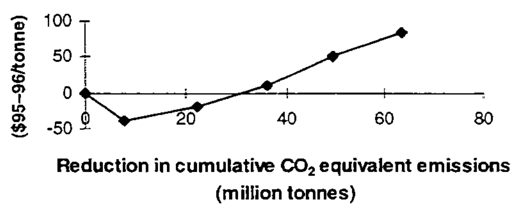
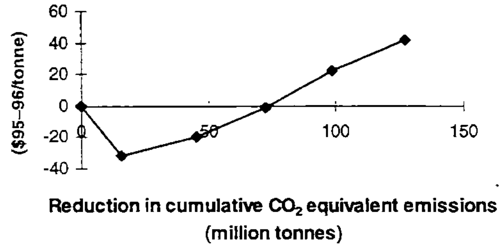



FIGURE 4.4 FUEL SAVING TECHNOLOGY: MARGINAL COSTS FOR 2015




*Source* BTCE estimates.

# CHAPTER 4 ACCELERATED INTRODUCTION OF FUEL SAVING TECHNOLOGY

## BACKGROUND

The fuel intensity of the Australian passenger vehicle fleet is improving, but at a very slow rate. Fleet fuel intensity declined from 11 litres per 100km to 9 litres per 100km between 1979 and 1990. BTCE projections of improvements in base case fuel efficiency (the inverse of fuel intensity) are about 20 per cent between 1996 and 2015.

Increased fuel efficiency 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, this instrument also reduces the cost of operating vehicles.

Prototype vehicles already in existence can achieve fuel efficiencies that are three times current levels by drawing on improvements in aerodynamics, engine performance and 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). Because consumers are offered a choice, however, penetration of new technology vehicles into the fleet is likely to be relatively slow. Under the 'corporate average fuel efficiency' (CAFE) scheme, the US government and car manufacturers coordinate research aimed at improving average 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

Australian fleet fuel efficiency would change. It was therefore decided to assess a policy instrument that permitted future developments to be more easily assessed. 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.

NELA (1991, p. 71) suggested 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 will take some years to implement. The instrument analysed here introduces relatively easy standards in 1996 and then lowers the mandatory fuel intensities annually until 2005. After 2005, fuel efficiency improvements occur at a rate equal to the base case except where the limits of fuel efficiency have been reached. The standards for 'snapshot' years are presented in table 4.1 and the those for intermediate years are based on equal increments. These standards are set in terms of cycle test results (EPAV 1991, p. 21) rather than on-road conditions that are thought to be 20 per cent higher than the cycle test.

TABLE 4.1 ASSUMED AVERAGE CYCLE TEST[a] INTENSITY STANDARDS

*(litres per 100 kilometres)*

| *Year* | *20* | *40* | *60* | *80* | *MTS* |
|---|---|---|---|---|---|
| 1995 | 8.8 | 8.8 | 8.8 | 8.8 | 8.8 |
| 2000 | 8.03 | 7.62 | 7.22 | 6.81 | 6.4 |
| 2005 | 7.25 | 6.44 | 5.63 | 4.82 | 4.01 |
| 2010 | 6.64 | 5.99 | 5.33 | 4.67 | 4.01 |
| 2015 | 6.03 | 5.53 | 5.02 | 4.52 | 4.01 |

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

*Sources* BTCE estimates and DeCicco & Ross (1994).

Five intensity levels are specified in table 4.1, with the maximum technology scenario (MTS) envisaging new car fuel intensities to be half their 1995 values by 2005. The remaining four intensities are 20, 40, 60 and 80 per cent of the maximum technology scenario. In estimating the effects of this policy a different fuel intensity was used for each vehicle class. The MTS results in the fuel intensity of large vehicles falling from 12 litres per 100km to 6 litres per 100km and the fuel intensity of small vehicles falling to below 3 litres per 100km.

Vehicle classes are those specified in the ITS/BTCE household travel model and include all sizes from micro to large, four-wheel drives (4WDs), people-movers and light commercial vehicles (LCVs) used as substitutes for cars.

While the actual standards would be mandatory, it was assumed that the 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 processes and consumer demand.

In this chapter, costs are expressed in 1995–96 Australian dollars (A$1995–96).

## METHODOLOGY

Two contradictory factors affect the potential reduction in greenhouse gas emissions resulting from an accelerated introduction of fuel efficient technology. Emissions will fall because of the reduced fuel consumption of new cars (the technology effect). But the increase in fuel efficiency will simultaneously make travel cheaper and may induce increased travel (often called the 'rebound' effect). The overall change in emissions is the sum of these two effects. The BTCE CARMOD model described in chapters 1 and 2 was the basis for the calculation of the technology effect. However, the change in travel behaviour was derived from the ITS/BTCE model.

Marginal and total cost curves are derived from the resource costs of the accelerated technology instrument. These costs are the sum of resource fuel costs, resource vehicle costs, insurance, cost of extra travel, loss of fuel profits, and health and accident costs.

In addition to the overall costs, the analysis includes separate calculations of the costs incurred by each sector; consumers, producers, government and externalities. Consumers gain from the retail cost of the fuel savings and the extra travel undertaken due to the rebound effect but incur the retail cost of the new technology vehicles and insurance cost increases. Fuel producers lose some profit. Government loses fuel excise revenue but gains sales tax revenue on the new vehicles. Health and accident costs are externalities.

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 and 35 cents per litre resource cost). While consumers gain the full retail value of the fuel savings, the government loses the excise revenue. The net 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 & Ross (1994) 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 10 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:

$$\%\Delta price = 1.5(0.0107\%\Delta fi + 0.001307\%\Delta fi^2 + 0.00001945\%\Delta fi^3)$$

where $\%\Delta price$ per cent increase in vehicle price

$\%\Delta fi$ per cent decrease in fuel intensity

The cost analysis considered only the change in resource cost of the vehicles (excluding sales tax). However, vehicle purchasers face the retail cost of the new technology vehicles but the government collects the change in sales tax revenue. The vehicle price increase also is 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. The gain to vehicle owners from the extra travel is estimated using the 'rule-of-a-half' (Williams, 1977). This gain is equal to the increase in travel multiplied by half the fuel saving per kilometre. Also estimated is the loss of revenue experienced by fuel producers due to the fall in fuel consumption, arbitrarily assuming that 2 per cent of the lost revenue is lost profit.

Externality effects such as health, accidents and congestion also generate costs to the community. For example, any fall in fuel consumption will cause a proportional reduction in noxious emissions such as carbon monoxide, resulting in a fall in health costs.

Reduced health costs from non-$CO_2$ emissions (resulting from the fall in fuel consumption) were included in the analysis. If emission standards continue to be set in grams per kilometre, then significant fuel savings would allow manufacturers to ease off on emission controls. That is, emission standards for new cars would need to be specified in grams per litre to ensure that health benefits were achieved, much as truck emission standards are expressed in grams per kilowatt hour.

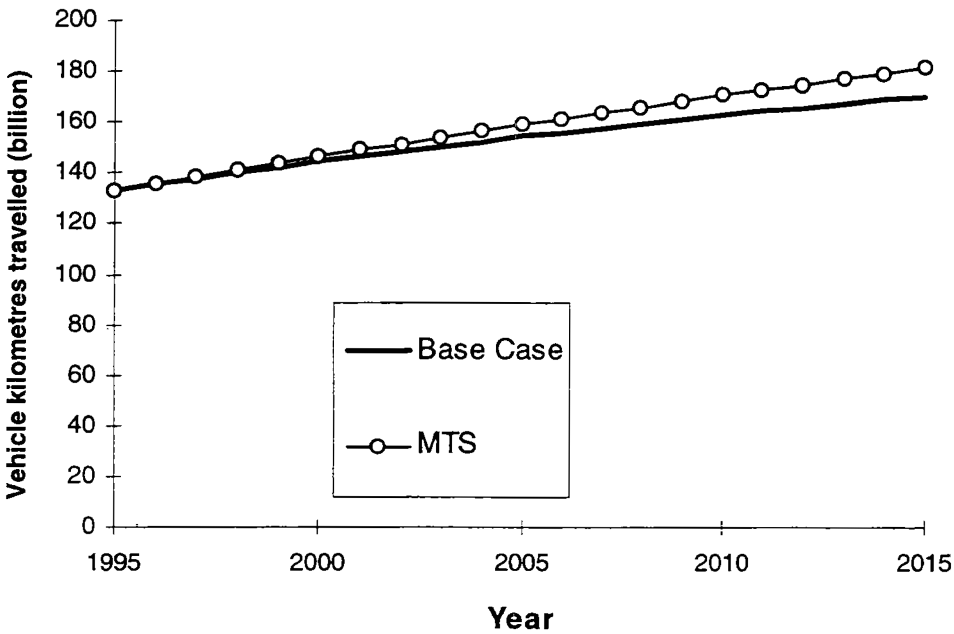
Accident costs relate directly to vehicle kilometres travelled: as travel increases so does the number of accidents. Unit health and accident costs are detailed in appendix III. While there will be some increase in congestion costs due to any increase in travel, it was not possible to estimate this cost with any degree of confidence and it has been omitted from the analysis.

Mandatory standards would require enforcement, involving fuel intensity tests on all new models entering the Australian market each year. Because 200 to 300 new models are introduced every year, the cost of testing one car in each vehicle type would be relatively small. This would especially be so if fuel intensity testing were to be incorporated with the emissions testing program currently conducted on new vehicles. As this cost is negligible it was not included in the analysis.

## RESULTS

Total travel increases because improved fuel efficiency makes travel less expensive once the vehicle purchasers have bought the new technology vehicles. Figure 4.5 shows the travel undertaken in both the base case and the maximum technology scenario. By 2015 the difference between the base case and the MTS is about 7 per cent in terms of vehicle kilometres.

FIGURE 4.5 VEHICLE KILOMETRES TRAVELLED FOR BASE CASE AND MTS, 1996–2015

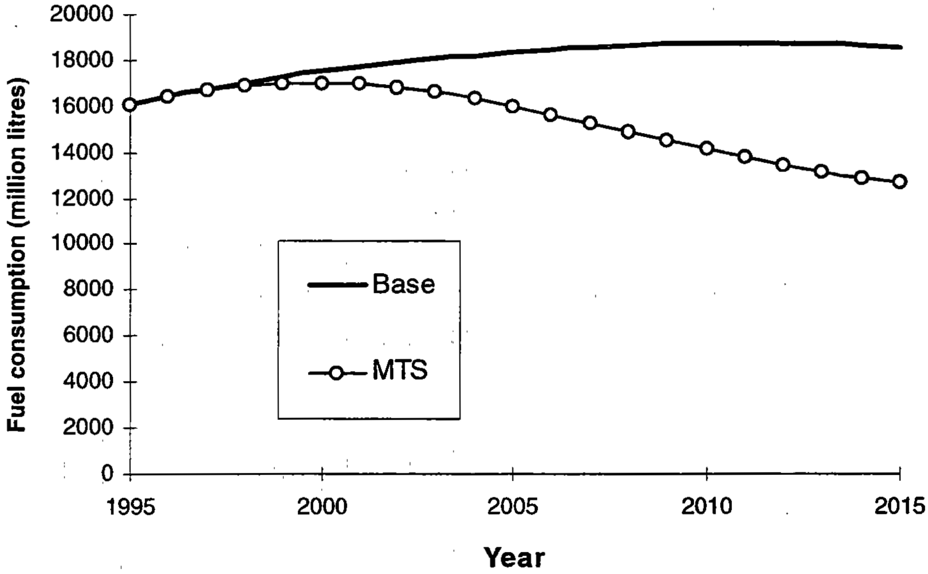



*Source* BTCE estimates.

Despite the increase in travel, the volume of fuel consumed over the period falls significantly (see figure 4.6). The difference between the base case 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 base case. For the MTS, fuel consumption in 2015 even falls below that of 1995, in spite of a 7 per cent increase in travel over the 20 years.

Because fuel consumption falls, greenhouse gas emissions also fall, particularly in the maximum technology scenario but also for the other intensity levels. Table 4.2 presents the $CO_2$ equivalent emission reductions compared to the base case for each of the intensity levels in the reference years.

FIGURE 4.6 FUEL CONSUMPTION FOR BASE CASE AND MTS, 1996–2015




*Source* BTCE estimates.

TABLE 4.2 DECREASE IN GREENHOUSE GAS EMISSIONS OVER BASE CASE

*(million tonnes)*

| *Intensity* | *2000* | *2005* | *2010* | *2015* |
|---|---|---|---|---|
| 20 | 0.3 | 2.4 | 7.6 | 15.5 |
| 40 | 0.8 | 7.0 | 22.4 | 45.0 |
| 60 | 0.3 | 11.2 | 36.2 | 72.6 |
| 80 | 0.7 | 15.1 | 49.5 | 99.0 |
| MTS | 2.1 | 19.3 | 63.6 | 127.5 |

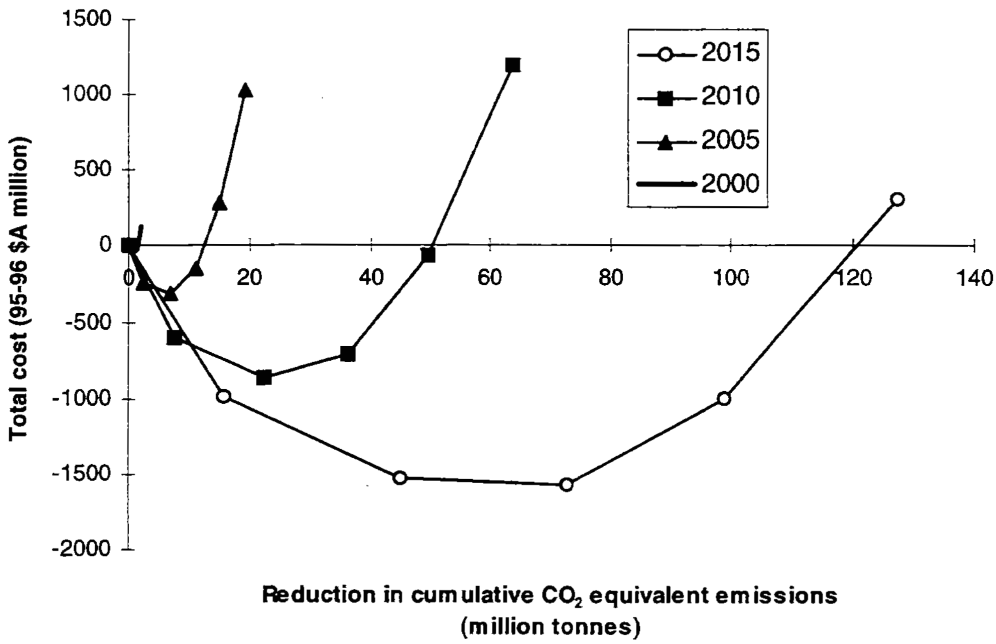
*Note* Base case emission levels are given in appendix II.

*Source* BTCE estimates.

The marginal cost curves in figures 4.1 to 4.4 show that large improvements in emissions are achievable at relatively low cost, particularly in the year 2015 when over 90 per cent of the fleet is projected to consist of new technology vehicles. Marginal costs fall progressively from $400/tonne in the maximum technology scenario in 2000 to below $40/tonne in 2015. Marginal costs are negative for the 20 and 40 per cent intensity levels for all 'snapshot' years and are also negative at the 60 per cent and 80 per cent intensity levels in the later 'snapshot' years.

Figure 4.7 shows the total costs for each of the snapshot years. For the 20, 40, and 60 per cent intensity levels, the policy of mandating greater fuel efficiency is one of 'no regrets', that is, net social costs are negative, so that the community is better off. At higher intensity levels (80 per cent and MTS) total social costs are positive but are fairly small and falling and in the years beyond 2015 even the higher intensity levels may yield negative net social costs. This fall in total costs is caused by the dominance of fuel savings over new vehicle costs. In 1996, the costs include the 1996 model new vehicles and the fuel savings from those vehicles in 1996. In 1997, costs include the 1997 model new vehicles and the fuel savings from both the 1996 and 1997 models. In later years, most of the fleet will have the fuel saving technology and therefore generate fuel cost savings to owners while only people purchasing new vehicles in that year will experience the capital costs.

FIGURE 4.7 TOTAL COST OF 'FUEL SAVING TECHNOLOGY' INSTRUMENT FOR 2000, 2005, 2010 AND 2015



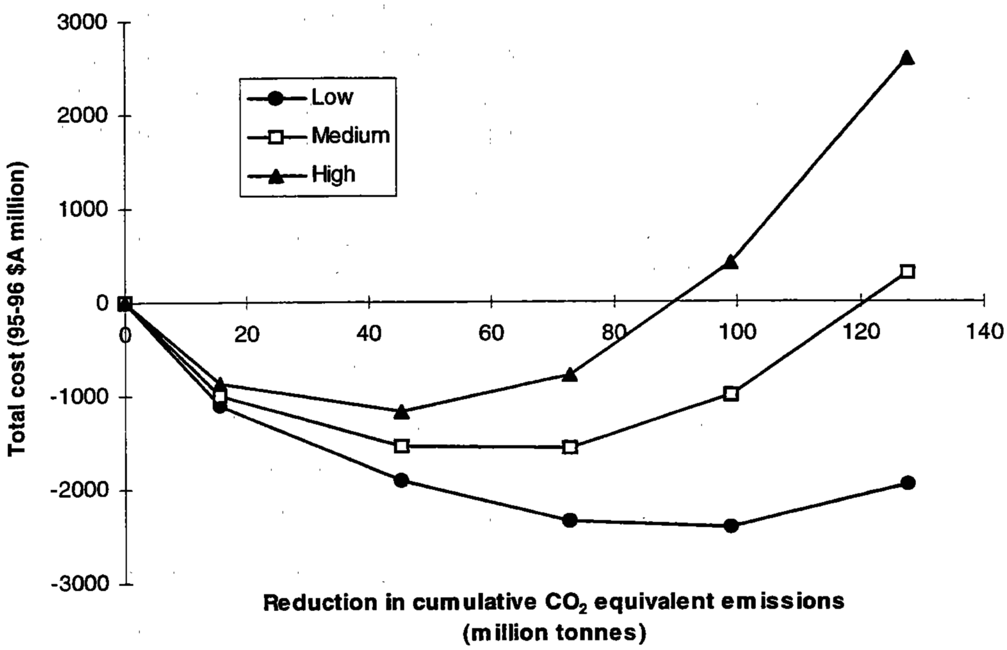

*Source* BTCE estimates.

## Sensitivity testing

Sensitivity testing was performed on two factors: the price of new vehicles and the discount rate. To test the sensitivity of the overall result to vehicle price the costs were re-estimated with the change 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 by $300m to $2 600m for the MTS, the 33 per cent decrease in the change in vehicle price resulted in the instrument producing negative costs at all intensities in the year 2015. Figure 4.8 shows the total costs for each vehicle price in 2015.

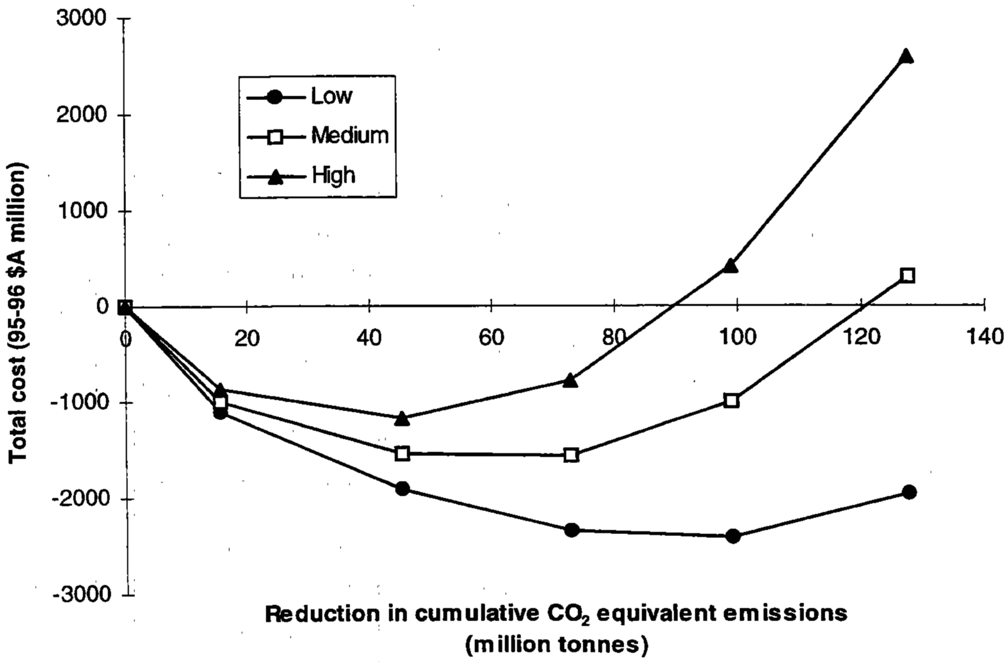
The analysis was based on a discount rate of 10 per cent and sensitivity testing considered 5 and 15 per cent. A discount rate of 5 per cent results in the benefits gained in later years having a relatively larger weighting than at the 10 per cent discount rate, resulting in lower costs and larger benefits. The reverse is true for the 15 per cent discount rate where the fuel saving benefits in later years are diminished.

FIGURE 4.8 SENSITIVITY TO CHANGES IN VEHICLE PRICE: TOTAL COSTS IN 2015




*Source* BTCE estimates.

FIGURE 4.9 SENSITIVITY TO CHANGES IN DISCOUNT RATE: TOTAL COSTS IN 2015




*Source* BTCE estimates.

## EQUITY ISSUES

Vehicle owners in particular experience benefits due to the large fuel cost savings and benefits due to the extra travel exceeding the vehicle price increase for the lower intensity levels. This result suggests that mandatory standards should not in fact be necessary to legislate these standards and that consumers would already be demanding fuel saving technologies from manufacturers.

Lovins & Lovins (1995) and Train (1985), although allowing for a wide range of discount rates generally observe that vehicle owners have a high discount rate. This leads to those owners not valuing future fuel cost savings highly enough to outweigh the additional capital cost of the vehicle achieving mandatory standards. The Government (that is, tax payers generally) would experience some loss of revenue as the loss of fuel excise would be likely to exceed the increase in sales tax revenue from new vehicles. Finally, there is some loss of revenue experienced by fuel production companies due to the fall in fuel consumption. Table 4.3 details the incidence of costs on consumers, producers, government and externalities. The specific costs in each of these categories are presented in table 4.16 in appendix IV.

TABLE 4.3 COMPOSITION OF TOTAL COSTS TO 2015

*($1995–96 million)*

| | *20* | *40* | *60* | *80* | *MTS* |
|---|---|---|---|---|---|
| Consumer | -2 484 | -4 386 | -5 692 | -6 333 | -6 127 |
| Producer | 50 | 97 | 141 | 185 | 234 |
| Government | 1 265 | 2 350 | 3 302 | 4 119 | 4 959 |
| Externalities | 178 | 404 | 683 | 1 032 | 1 249 |
| **Total** | **-991** | **-1 535** | **-1 566** | **-998** | **315** |

*Source* BTCE estimates.

...AT A GLANCE

## EMISSION CONTROL TECHNOLOGY

Greenhouse gas emissions can be reduced by controlling non-$CO_2$ (noxious) emissions from cars. A policy measure directed at curbing noxious emissions can be implemented either as a substitute for, or as a complement to, measures designed to reduce fuel usage.

## KEY FEATURES

- By mass emitted, $CO_2$ is the primary emission produced by passenger vehicles. Automobile exhaust emissions also include small amounts of the noxious gases carbon monoxide, nitrogen oxides, and non-methane volatile organic compounds. However, many of these noxious emissions are much more potent greenhouse gases than $CO_2$ itself. Controlling these emissions can thus contribute to reducing total $CO_2$ equivalent greenhouse gas emissions.
- Four emission control measures are 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.
- Introduction of the four technologies reduces overall greenhouse gas emissions (in $CO_2$ equivalents) from cars by about 7 per cent by 2015.
- As a side benefit, noxious emissions in Australian cities are reduced significantly.
- Marginal costs are positive and rise fairly quickly as additional measures are introduced. They are also significantly lower in the longer term, as new cars with the extra emission controls spread through the fleet.

FIGURE 5.1 EMISSION CONTROL TECHNOLOGY: MARGINAL COSTS FOR 2000

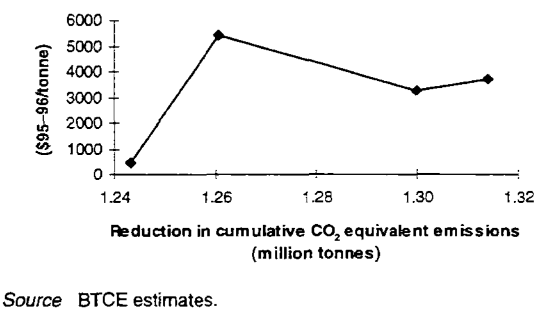
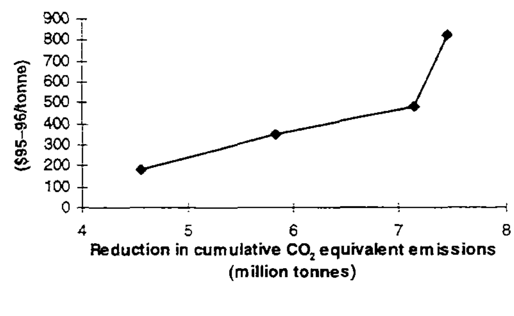



FIGURE 5.2 EMISSION CONTROL TECHNOLOGY: MARGINAL COSTS FOR 2005




*Source* BTCE estimates.

FIGURE 5.3 EMISSION CONTROL TECHNOLOGY: MARGINAL COSTS FOR 2010

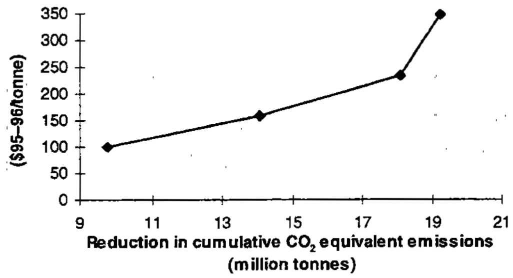
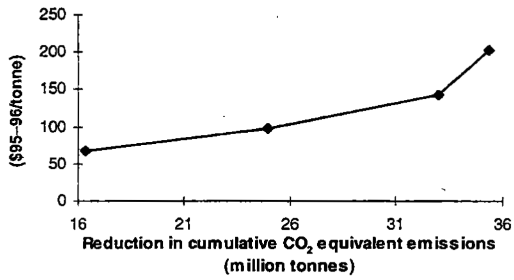



FIGURE 5.4 EMISSION CONTROL TECHNOLOGY: MARGINAL COSTS FOR 2015




*Source* BTCE estimates.

# CHAPTER 5 EMISSION CONTROL TECHNOLOGY

## BACKGROUND

New technology can reduce emissions of greenhouse gases in a number of ways; for example, by improving the fuel efficiency of vehicles. However, technological solutions can also be used more directly to reduce emission levels themselves.

Carbon dioxide ($CO_2$) is the major greenhouse gas, in terms of mass, that is emitted by motor vehicles. However other gases emitted by passenger vehicles—including methane ($CH_4$), non-methane volatile organic compounds, 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 emissions have more than 24 times (table I.1) the warming effect of an equal mass of $CO_2$ emissions.

Emission control technologies are usually designed to reduce non-$CO_2$ gases, whereas reductions in $CO_2$ are more directly achievable through increased fuel efficiency. The four emission control technologies examined in this chapter affect non-$CO_2$ emissions. Because some of these non-$CO_2$ gases are noxious to humans in significant concentrations, their reduction can have spin-off health benefits to society, particularly in urban areas.

### Catalyst replacement

The efficiency of catalytic converters in reducing exhaust emissions of carbon monoxide (CO), hydrocarbons (HCs) and nitrogen oxides ($NO_x$) 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 unpub., EPA NSW 1995 and Carnovale et al. 1991) for the emission performance of catalytically controlled Australian vehicles are given in table 2.5 of this working paper. The magnitudes of the deterioration rates imply that after eight to 10 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 as a first step, the Government requires that from 1997 onwards, all catalytically controlled Australian cars must have their catalyst replaced every eight years. This policy would require that all catalyst vehicles eight years of age or older in 1997 have the catalyst replaced in that year. In each following year, any vehicles that have not had the contents of their catalytic converter renewed for at least eight years, must have catalyst replacements in that year.

**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. 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 to be burned' (Carnovale et al. 1991, p. 51).

Tests by the USEPA (1990, 1993) have since shown that running loses 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) found late model vehicles to 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 US). 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).

Accurate measurements of running losses have not yet been done in Australia. Overseas studies 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 yet been detected, the derivation of greenhouse abatement costs is necessarily rather speculative.

Although the cost estimates 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 in this chapter 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 base case 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, the measure analysed in this chapter assumes that fuel specifications are fixed, and that emission reductions are achieved purely through vehicle engineering.

By focussing on running loss reductions, it is likely that stimulated 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, since OBD may not be required to reduce running losses. However, 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 base case incorporates revisions to the Australian Design Rules (ADRs) for new vehicles scheduled to be introduced from 1997 that reduce levels of noxious emissions (table 2.3). In the base case, 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 is 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, 0.17 g/km for HC and 0.14 g/km for $NO_x$ be imposed in 2000 (down from 2.1 g/km for CO, 0.26 g/km for HC and 0.63 g/km for $NO_x$). The emission standards proposed in the scenario 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 assumed above to be used 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 measures evaluated in this chapter assume changes solely to base case emission rates and not to base case fuel efficiency. That is, the policy instrument assumes that 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, the introduction of new emission control technology without increasing fuel consumption would probably be the most difficult for catalyst heaters. There are also some doubts over the long-term use of catalyst heaters, with the effective lifetime of the catalyst possibly being reduced.

## METHODOLOGY

Incremental reductions in greenhouse gas emissions from passenger vehicles are achieved through the sequential introduction of the four technologies outlined above. These technologies essentially represent varying degrees of intensity of application of an emissions control policy measure.

The first level of implementation involves the mandatory replacement of catalysts every eight years, for all vehicles equipped with a catalytic converter. The second level of intensity for the instrument calls for catalyst replacement plus the requirement that new cars be engineered so as to reduce running losses (evaporative HC emissions during engine operation). The third intensity level requires the introduction of new vehicle design standards in 2000, requiring improved emission performance across all noxious gases. The fourth intensity level of the instrument 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 any monitoring or enforcement;
- new vehicle components; and
- production overheads (such as additional labour costs).

Touche Ross (1995) 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 BTCE assumption that the technology packages should be treated as neutral with respect to 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 BTCE analysis includes the following assumptions in estimating incremental costs:

- The average cost of catalyst replacement is A$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 second intensity level of the instrument consists of level 1 (the regular replacement of catalysts) plus the reduction of running losses. The incremental cost of implementing the second intensity level is assumed to be A$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 (A$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 third intensity level of the instrument consists of the technologies of level 2 plus the introduction of new vehicle design standards. The incremental cost of implementing the third intensity level is assumed to be A$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 around 40 per cent. Averaging across results for different vehicle classes gives an estimate of around 256 ECU per vehicle (Touche Ross 1995, Annexe I) 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 all new cars manufactured after 2000 to include catalyst heaters to reduce cold start emissions) is assumed to be A$190 extra per vehicle. The A$190 value is an incremental cost, composed of the cost of providing the new component (the heater) minus the cost of components installed under the second intensity level of the instrument that are superseded by catalyst heaters. As part of the technology package to meet the reduced emission standards, Touche Ross (1995, p. 92) 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 engineering the vehicle so that the catalyst volume is close to the exhaust manifold, where the heat generated speeds up the catalyst attaining its operating temperature. It is assumed that close-coupling is no longer needed if catalyst heaters are fitted. Using an average cost for catalyst heaters of 179 ECU per vehicle

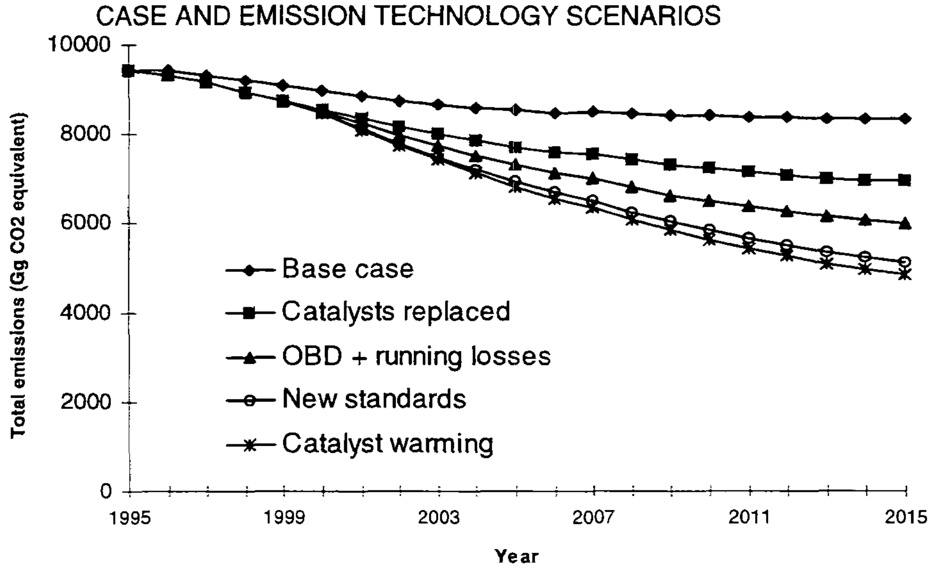
(Touche Ross 1995, Annexe I), results in an estimated incremental cost of 119 ECU per vehicle in the absence of close-coupling.

Externality effects were also included in the analysis, to the extent that environmental damage costs due to vehicle emissions are available. Approximate unit damage costs (dollars per kilogram of gas emitted) have been derived by reviewing the literature (appendix III). The estimated damage costs, which relate primarily to health losses caused by air pollution, should only be treated as likely order of magnitude values, since the difficulty in estimating such costs leads to a wide variation in the results of the different studies reported in the literature.

The 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 III). 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 CARMOD.

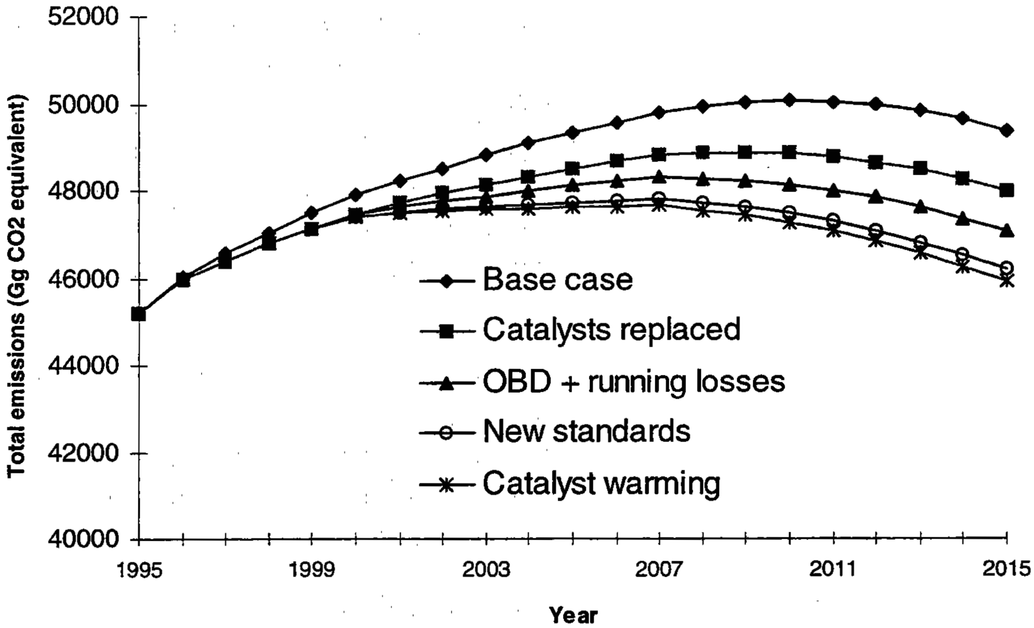
Costs (including offsetting benefits of reductions in noxious emissions) have been cumulated in order to match the cumulative effects of emission reductions achieved through the introduction of the four technologies. Marginal costs for the years presented (2000, 2005, 2010 and 2015) are 'snapshots' which 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.

FIGURE 5.5 PROJECTED NON-$CO_2$ GREENHOUSE GAS EMISSION LEVELS FOR BASE CASE AND EMISSION TECHNOLOGY SCENARIOS




OBD On-Board Diagnostics
*Source* BTCE estimates.

FIGURE 5.6 PROJECTED TOTAL GREENHOUSE GAS EMISSION LEVELS FOR BASE CASE AND EMISSION TECHNOLOGY SCENARIOS




OBD On-Board Diagnostics

*Source* BTCE estimates.

TABLE 5.1 NOXIOUS EMISSION DECREASES OVER BASE CASE IN VARIOUS YEARS: PASSENGER CARS

*(Gg of gas)*

| *Gas* | *Intensity level* | *Year* | | | |
|---|---|---|---|---|---|
| | | *2000* | *2005* | *2010* | *2015* |
| *CO* | | | | | |
| | 1 | 265 | 486 | 695 | 804 |
| | 2 | 265 | 486 | 695 | 804 |
| | 3 | 270 | 528 | 771 | 906 |
| | 4 | 270 | 574 | 860 | 1029 |
| *$NO_x$* | | | | | |
| | 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 |

*Note* For 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.

TABLE 5.2 TOTAL GREENHOUSE GAS EMISSION DECREASES OVER BASE CASE IN VARIOUS YEARS: PASSENGER CARS

*(Gg of $CO_2$ equivalent)*

| *Intensity* | *Year* | | | |
|---|---|---|---|---|
| *level* | *2000* | *2005* | *2010* | *2015* |
| 1 | 405 | 815 | 1187 | 1390 |
| 2 | 443 | 1216 | 1908 | 2337 |
| 3 | 483 | 1600 | 2568 | 3213 |
| 4 | 484 | 1702 | 2764 | 3485 |

*Notes* 1. For 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.

2. Emissions converted to $CO_2$ equivalent using 100 year GWP values (in appendix table I.1).

*Source* BTCE estimates.

TABLE 5.3 CUMULATIVE GREENHOUSE GAS EMISSION DECREASES OVER BASE CASE BY VARIOUS YEARS: PASSENGER CARS

*(Gg of $CO_2$ equivalent)*

| *Intensity* | *Year* | | | |
|---|---|---|---|---|
| *level* | *2000* | *2005* | *2010* | *2015* |
| 1 | 1243 | 4551 | 9750 | 16371 |
| | (0.53) | (0.95) | (1.34) | (1.68) |
| 2 | 1261 | 5845 | 14036 | 24978 |
| | (0.54) | (1.22) | (1.93) | (2.56) |
| 3 | 1300 | 7155 | 18112 | 33042 |
| | (0.55) | (1.46) | (2.49) | (3.38) |
| 4 | 1314 | 7463 | 19218 | 35368 |
| | (0.56) | (1.56) | (2.64) | (3.62) |

*Notes* 1. For 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.

2. Emissions converted to $CO_2$ equivalent using 100 year GWP values (in appendix table I.1).

3. Figures in parentheses are percentage decreases in cumulative $CO_2$ equivalent emissions over the base case.

*Source* BTCE estimates.

## RESULTS

Emission technology measures have the potential to reduce projected emissions substantially by 2015 (figures 5.5, 5.6). Results for emission reductions in 'snapshot' years are presented in tables 5.1 and 5.2. At the highest intensity level of the instrument, *total* emissions ($CO_2$ plus non-$CO_2$) are reduced from base case levels by 3.6 per cent of the cumulated $CO_2$ equivalent emissions over the period 1996 to 2015 (table 5.3). The reduction in *total* greenhouse gas emissions for 2015 is more than 7 per cent of the base case emissions for that year.

Reductions in annual tonnages of *noxious* emissions (table 5.1) increase steadily up to 2015. Noxious emissions in $CO_2$ equivalents for 2015 fall by over 40 per cent compared to the base case. Over the period 1996 to 2015, cumulative non-$CO_2$ emissions (in $CO_2$ equivalents) fall by 24 per cent compared to the base case.

## Costs

The pollution control equipment required to implement the instrument at the highest intensity level costs around 3 per cent of the average purchase price of a new car. The cost to consumers could be about half a billion dollars per year. Inclusion of the health benefits due to lessening air pollution reduces total costs, on average, by about 1.5 per cent.

TABLE 5.4 TOTAL COSTS UP TO AND INCLUDING 'SNAPSHOT' YEARS FOR EMISSIONS TECHNOLOGY INSTRUMENT

*($1995-96 million)*

| *Intensity level* | *Year* 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|
| 1 | 542 | 813 | 986 | 1098 |
| 2 | 635 | 1266 | 1669 | 1927 |
| 3 | 764 | 1895 | 2617 | 3081 |
| 4 | 816 | 2149 | 3002 | 3550 |

*Notes* 1. For 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.
2. Current values for all years discounted at 10 per cent.

*Source* BTCE estimates.

At the highest intensity level, the 'total cost' (NPV of the cost stream over the period 1996 to 2015) of the emissions technology instrument is estimated as about A$3.6 billion (table 5.4). The average cost (total costs divided by cumulative emission reductions) over the period is $67, $77, $93 and $100 per tonne (of $CO_2$ equivalent emissions abated) for the respective intensity levels.

The resulting marginal costs (addition to total costs between intensity levels divided by the change in cumulative emission reductions) for the instrument are given for 'snapshot' years in table 5.5, and the results are illustrated for 2015 in figure 5.7.

TABLE 5.5 MARGINAL COSTS OF REDUCING EMISSIONS THROUGH EMISSION CONTROL TECHNOLOGY

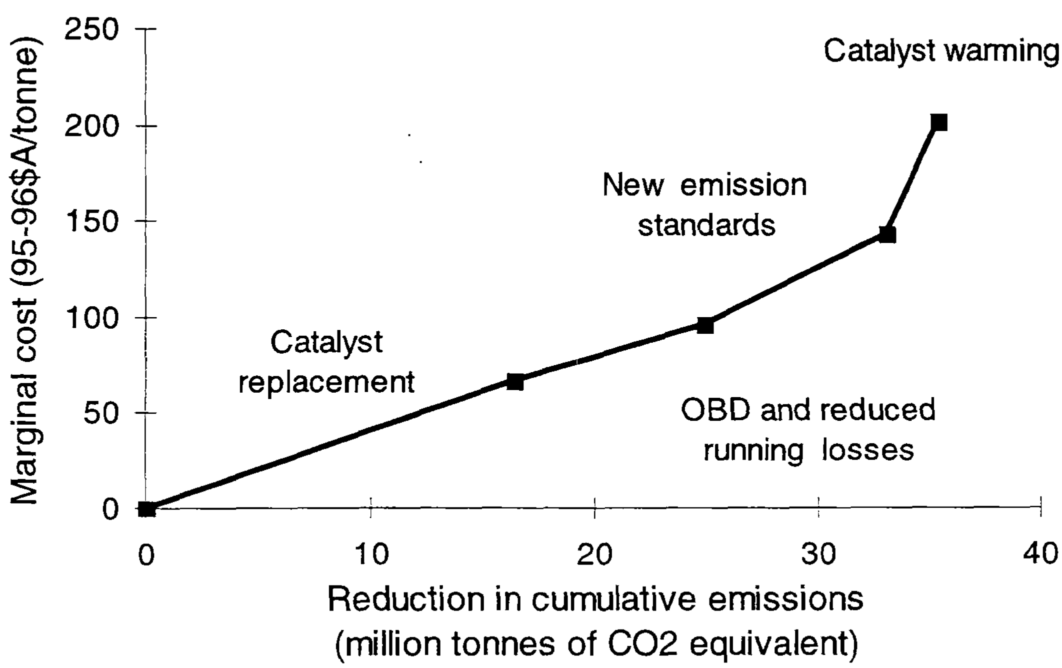
*($1995–96 per tonne of reduction in cumulative $CO_2$ equivalent emissions)*

| *Intensity level* | *Year* 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|
| 1 | 436 | 179 | 101 | 67 |
| 2 | 5409 | 350 | 159 | 96 |
| 3 | 3254 | 480 | 233 | 143 |
| 4 | 3707 | 826 | 348 | 201 |

*Notes* 1. For 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.
2. 1996 dollar values for all years discounted at 10 per cent.
3. Costs are very high for 2000 because it is assumed that the new emission technologies only become available in that year.

*Source* BTCE estimates.

FIGURE 5.7 MARGINAL COSTS IN 2015 OF INTRODUCING EMISSION CONTROL TECHNOLOGIES




*Note* $1995–96 values discounted at 10 per cent.

OBD On-Board Diagnostics.

*Source* BTCE estimates.

### Sensitivity testing

A discount rate of 10 per cent was used in the analysis. To test the sensitivity of the results to the discount rate, marginal costs were re-estimated using rates of 5 and 15 per cent (table 5.6). 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 are 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 proportionately on the costs assumed for equipping passenger vehicles with the different technologies. Touche Ross (1995, p.17) found it to be '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 reducing emission rates to considerably below those assumed for this chapter. The ranges provided by Touche Ross (1995) for the costs of various components of reducing emission rates packages imply that the average cost for the highest level of this chapter's instrument is likely to be within 50 per cent (above or below) of the value derived above.

TABLE 5.6 MARGINAL COSTS OF REDUCING EMISSIONS THROUGH EMISSION CONTROL TECHNOLOGY, 2015

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

| *Intensity level* | *Discount rate (per cent)* 5 | 10 | 15 |
|---|---|---|---|
| 1 | 97 | 67 | 50 |
| 2 | 162 | 96 | 61 |
| 3 | 240 | 143 | 91 |
| 4 | 339 | 201 | 128 |

*Source* BTCE estimates.

## EQUITY ISSUES

The costs of requiring emission control technologies fall primarily on car owners. New car buyers will initially bear most of the additional cost, but it will be passed on to subsequent used car buyers through higher vehicle prices.

...AT A GLANCE

## COMPULSORY TUNING OF ENGINES

Greenhouse gas emissions can be caused by the inefficient operation of vehicle engines. Compulsory engine tuning of passenger vehicles can reduce both fuel use ($CO_2$ emissions) and pollutant (non-$CO_2$) emissions, both of which comprise greenhouse gases.

## KEY FEATURES

- It is assumed that all passenger vehicles are required to undergo two engine tunings per year. Starting with the oldest cars in the fleet, the analysis is progressively extended to cars of more recent vintage.
- Potential benefits in greenhouse gas reductions are fairly limited. A maximum of 15 million cumulative tonnes can be achieved by 2015.
- Marginal costs are quite high; ranging from about $600 to about $6 000 per tonne of greenhouse gas emissions avoided. For cars manufactured after 1991, marginal costs increase dramatically, with little additional greenhouse abatement benefit.

FIGURE 6.1 MARGINAL COSTS—2000

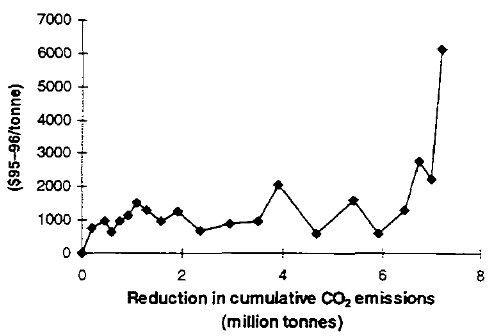



FIGURE 6.2 MARGINAL COSTS—2005

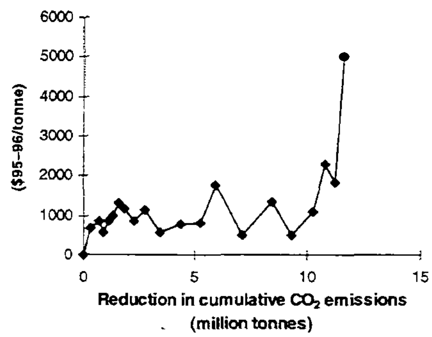



FIGURE 6.3 MARGINAL COSTS—2010

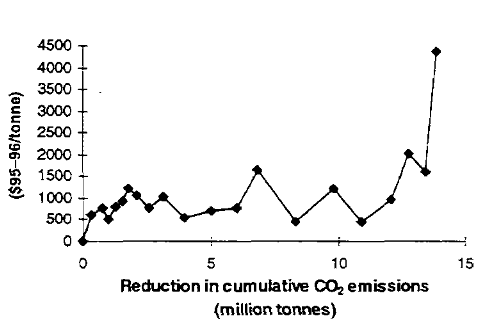
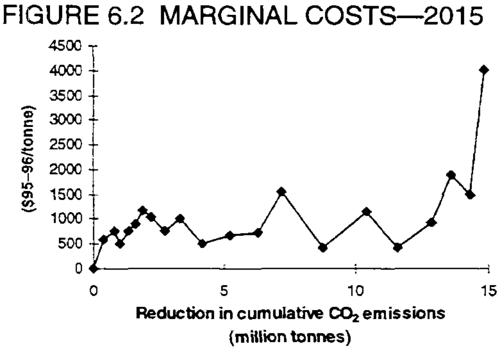



FIGURE 6.2 MARGINAL COSTS—2015




*Source* BTCE estimates.

# CHAPTER 6 COMPULSORY TUNING OF ENGINES

## BACKGROUND

Random and compulsory tests of vehicle emissions provide a means of controlling excessive emissions. However, testing of vehicle emissions requires the setting of standards against which the tests can be performed. In the case of noxious emissions, standards can be set on the basis of health effects and dose-response relationships.

Inspection and maintenance (I&M) programs may be implemented in a centralised or decentralised manner. In centralised programs vehicles are tested at designated facilities, whereas in decentralised programs vehicles are tested at local service stations. Both types of program have been implemented in the USA. The programs involve various degrees of inspection of emission-producing systems in vehicles and compulsory repair (usually subject to fixed monetary limits) if emissions fail to conform to standards.

In contrast, the policy instrument assessed in this chapter requires the compulsory tuning of engines in all designated vehicles.

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. Prescription of minimum fuel efficiency standards is an option explored in chapter 4 of this working paper.

An alternative is to minimise the fuel used by all vehicle types, irrespective of the fuel efficiency level for which they were designed. A plausible method of doing so is to ensure that vehicle engines are tuned regularly. A 'greenhouse abatement' policy instrument analogous to testing for noxious emissions is therefore the compulsory tuning of passenger vehicles.

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

Compulsory tuning of vehicles can be expected to be more suited as a short term policy for reducing greenhouse emissions. Advancements in vehicle technology such as emission control equipment and on-board diagnostic devices, coupled with more stringent emission standards, mean that vehicles manufactured after 1991 have different tuning requirements and their potential for emission reductions from tuning is limited. As pre-1991 vehicles are progressively scrapped from the Australian car fleet, it could be expected that the benefits of a compulsory tuning program would decline. Indeed, some overseas studies on the cost-effectiveness of inspection and maintenance programs (Reitze 1979, McConnell 1990) have found that the benefits of such programs decline over time.

Compulsory tuning, like inspection and maintenance programs, is a fairly blunt instrument in that it imposes costs on all vehicles, whether fuel efficient or not. Its cost-effectiveness could be enhanced by some form of targeting.

There is considerable empirical evidence that emissions generally increase with age. 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 10 times higher than well maintained late model vehicles. Anilovich & Hakkert (1995, p. 11) and Bruno & 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.

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 & 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 & Cadle (1991) and Ashbaugh & Lawson (1991) which found that roughly half of CO emissions come from between 10–20 per cent of the fleet and that between 50–80 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 1–2 year old cars were high emitters.

The mean age of the Australian fleet in 1991 was 9.4 years while the median age was eight years. Table 6.1 shows the age distribution of the Australian fleet as at 1993. The table shows that over 50 per cent of the fleet is over nine years old. The age distribution of the Australian fleet suggests that engine tuning could have the potential to produce substantial reductions in emissions at least in the short term.

TABLE 6.1 PERCENTAGE OF FLEET BY AGE OF VEHICLES

| Vehicle age (years) | 15+ | 9–14 | 6–8 | 3–5 | 1–2 | less than 1 |
|---|---|---|---|---|---|---|
| Percentage of fleet (per cent) | 21 | 32 | 16 | 15 | 10 | 6 |

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

Marginal costs of emission reduction per tonne have been estimated for each vintage commencing with a category for 1971 and earlier (in this chapter, all references to 1971 vehicles include all prior vintages in the fleet) and progressively including all vintages up to 1991. Costs of reducing emissions in the 'snapshot' years 2000, 2005, 2010 and 2015 have been estimated in terms of 1995–96 dollars using three discount rates.

**Federal Office of Road Safety (FORS) In-Service Motor Vehicle Emissions Study**

The major data source was the In-Service Motor Vehicle Emissions Study conducted by FORS. The FORS study was at an advanced stage, but was not completed, at the time the BTCE analysis was carried out. Consequently only part of the data that were to be collected in the FORS study could be used.

The FORS study has several objectives which include the estimation of the total exhaust emissions of the current passenger vehicle fleet before and after tuning and to provide 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 600 vehicles, 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 respondents' income. About 70 per cent of the vehicles tested were manufactured in and after 1986 (catalyst equipped). The balance of 30 per cent were manufactured mainly between 1980 and 1985 (non-catalyst) but included several vehicles manufactured between 1972 and 1979. Vehicle testing commenced in May 1994 and was completed in December 1995.

Vehicles were tested when they were received at the testing station and again after they had been tuned as far as possible to manufacturers' specifications. The difference in emissions before and after tuning is an indicator of the maximum achievable reduction in emissions from vehicles of a particular type and vintage. Several tests were carried out including steady state idle tests and ADR 37/00 exhaust and evaporative emissions tests.

## METHODOLOGY

### Estimation of emission changes due to tuning

The data base of the FORS in-service motor vehicle emissions study was used to estimate changes in emissions and fuel consumption after tuning. The analysis is based on data relating to 446 vehicles (out of a total of 600 vehicles tested by FORS) which were available at the time it was carried out. The FORS emissions data are the most comprehensive and up to date available for Australia (a comprehensive analysis of the emissions data is expected to be published by FORS about mid-1996).

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

| | |
|---|---|
| Micro | (≤4 cylinders, < 1400cc) |
| 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). All of Mercedes, BMW, Rolls Royce, Jaguar, Audi, Bentley, Lexus, Daimler and Eunos plus Honda Legend/NSX (> 3000 cc), Volvo ≥2300 cc, Saab > 2100 cc. |

As part of contracted work for the BTCE, the Institute of Transport Studies at The University of Sydney's Graduate School of Business provided 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). Although the entire fleet was assigned to seven classes for the BTCE study, luxury vehicles were not tested as part of the FORS study. Post-tuning changes in emissions for the luxury class were therefore assumed to be equivalent to the average values for vehicles in the other six classes.

Scrappage rates of vehicles were calculated using the CARMOD model developed by the BTCE (chapter 1). 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 $NO_x$. Differences in fuel consumption (in litres per 100 km) before and after tuning were also calculated and converted to the equivalent amount of $CO_2$ in grams per km. 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 three 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 three values.

As 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 in the database developed for the BTCE study. These gaps (the change in emissions of a vehicle of a particular class and vintage) were filled by adopting the following estimation procedure. An 'all class' category was generated which involved averaging the changes in emissions for all vintages across classes (that is, the average of emission changes for all vintages from 1972 to 1995). To estimate a particular missing value, the changes in emissions of the four closest available vintages within the class to which the vehicle belongs (vehicles of four different vintages but of the same class) and the changes in emissions of the four closest vintages from the 'all class' category (vehicles of four different vintages averaged across classes) were averaged. The average value obtained by this process was used as the missing value.

Each missing value was therefore the average of eight values (unless there were less than four values in each class, which only occurred in the medium class). This method of estimating missing values takes account of the class effect (within each class, vehicles closest in vintage to the missing value would be expected to have similar emissions) and a vintage or state-of-technology effect (vehicles of different classes but of similar vintage would be expected to have similar emissions).

The estimation 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 by the BTCE targets the HC exhaust emissions only (and $NO_x$, CO and $CO_2$ exhaust emissions). According to estimates by EPA NSW (1994, p.6), only 40 per cent of HC emissions come from the exhaust. EPA NSW 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 1996, 74.2 cents per litre and average kilometres travelled by class, yields estimates of the monetary value of fuel savings.

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 in this study for such a possibility because the estimated average fuel savings per vehicle were 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 III). 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 value used for HC and $NO_x$ was \$0.07 per kg and for carbon monoxide \$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 V).

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 one hour and 20 minutes. The total amount of fuel consumed for travel and in the tuning process was assumed to be two 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]

Administration costs are estimated as 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 administration was estimated at $3.29 per vehicle.

The cost of inspecting premises 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.

The costs and benefits of compulsory tuning are summarised in table 6.2. Net costs of vehicle tuning are obtained by summing all costs and subtracting health and fuel saving benefits for the seven classes of vehicles comprising the Australian passenger car fleet.

The analysis of emissions data used in this study 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. The largest potential reductions in emissions can be achieved first in this way.

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1. Average cost estimates are: 3-hour major tune $189; 1½ hour minor tune $94; for each tuning, cost of parts $71 (Neil 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).

TABLE 6.2 COSTS AND BENEFITS OF VEHICLE TUNING

| *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. |
| *Benefits* | | | |
| Health benefits (HC and $NO_x$) | 0.05 | Per kg reduced | BTCE estimates (appendix III) |
| Average fuel saving benefit | 27.13 | Per vehicle per year | BTCE estimate |

*Source* BTCE estimates based on data from various sources.

## RESULTS

Marginal costs of emission reduction by engine tuning were calculated for vehicles of vintages ranging from 1971 and earlier, to 1991 (that is, 1971–72, 1971–73, 1971–74 etc. up to 1971–91).

Table 6.3 shows the cumulative reduction in emissions in terms of $CO_2$ equivalents for selected intensity levels for the years 2000, 2005, 2010 and 2015. The maximum cumulative reduction achievable is about 15 million tonnes by the year 2015. Table 6.4 sets out the corresponding marginal costs per tonne of $CO_2$ equivalent emissions avoided at a 10 per cent discount rate. The marginal costs range from approximately $600 to $6 000. As is evident from table 6.4 and figures 6.1 to 6.4, marginal costs rise dramatically with the inclusion of post-1986 vehicles.

TABLE 6.3 REDUCTION IN CUMULATIVE $CO_2$ EQUIVALENT EMISSIONS FOR SELECTED INTENSITY LEVELS

*(million tonnes)*

| *Intensity* | *2000* | *2005* | *2010* | *2015* |
|---|---|---|---|---|
| 1971–72 | 0.2 | 0.3 | 0.3 | 0.4 |
| 1971–75 | 0.8 | 1.1 | 1.2 | 1.3 |
| 1971–80 | 1.9 | 2.7 | 3.1 | 3.3 |
| 1971–86 | 5.4 | 8.4 | 9.8 | 10.4 |
| 1971–91 | 7.2 | 11.6 | 13.9 | 14.9 |

*Source* BTCE estimates; emissions data from FORS.

Figures 6.1 to 6.4 also show that marginal costs tend to rise and fall, but show an overall rising trend as more (and newer) vehicles are tuned. The rising trend in marginal costs can be clearly observed from the figures set out in table 6.4, which have been chosen to highlight this trend as the level of intensity is increased (moving down the table). As the potential for reducing emissions from newer vehicles is limited, marginal costs tend to rise rapidly as these vehicles are compulsorily tuned.

TABLE 6.4 MARGINAL COSTS OF REDUCING CUMULATIVE EMISSIONS

*($1995–96 per tonne of $CO_2$ equivalents)*

| *Vintages* | *1996–2000* | *1996–2005* | *1996–2010* | *1996–2015* |
|---|---|---|---|---|
| 1971–1972 | 739 | 654 | 611 | 590 |
| 1971–1975 | 960 | 849 | 793 | 766 |
| 1971–1980 | 1 277 | 1 119 | 1 040 | 1 002 |
| 1971–1986 | 1 596 | 1 348 | 1 219 | 1 159 |
| 1971–1991 | 6 112 | 5 022 | 4 359 | 4 027 |

*Source* BTCE estimates; emissions data from FORS.

Table 6.4 also shows that marginal costs decrease over time (moving across the table). It must be borne in mind that this analysis refers only to vehicles manufactured between 1971 (and earlier) 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 at a particular point in time. The fall in marginal costs over time is due in part to the smaller number of vehicles in the fleet over time. Many of the vehicles of early vintage (for example, 1971 to about 1985) would have been scrapped by 2015. Lower marginal costs over time also reflect the impact of discounting costs back over a longer period to the 1996 base year.

Some distinctive features may be observed from table 6.4 (and figures 6.1 to 6.4). For example, catalytic converters and unleaded petrol have been required for all new vehicles from 1986. Marginal costs therefore tend to rise rather steeply for post-1986 model cars because tuning produces relatively smaller reductions in emissions. It is also evident that compulsory tuning, if implemented, would be fairly short-lived because marginal costs rise rapidly as the number of older vehicles in the fleet declines.

Emission reductions for vehicles of a particular class and vintage have been calculated using values based on small samples of vehicles from the FORS database. These values have been applied to all vehicles of that particular class and vintage. This approach relies on the assumption that the average emission reduction for vehicles of a particular class and vintage tested matches closely the emission reduction for all other vehicles in that class and vintage in the fleet. It is not known to what extent the emission reduction potential of vehicles of particular classes and vintages deviate from the emission reductions observed in the tested vehicles. The level of uncertainty inherent in the results obtained is therefore not known.

### Sensitivity analysis

A 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 6.5, together with the medium (or most likely) values. Tables 6.6 and 6.7 show marginal costs based on low and high scenarios respectively.

TABLE 6.5 COSTS VARIED IN SENSITIVITY ANALYSIS

| *Activity incurring costs* | *High cost* | *Medium cost* | *Low cost* |
|---|---|---|---|
| Litres of fuel per vehicle | 6 | 4 | 2 |
| ($ / 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 and one set of parts | Two minor tunes plus one set of parts |
| ($ / year) | (449) | (354) | (259) |
| Number of tuning facilities inspected | 300 | 200 | 100 |
| ($ / 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 6.6 MARGINAL COSTS FOR LOW COST SCENARIO

*($1995–96/tonne)*

| *Intensity* | *2000* | *2005* | *2010* | *2015* |
|---|---|---|---|---|
| 1971–72 | 510 | 451 | 421 | 406 |
| 1971–75 | 664 | 587 | 548 | 529 |
| 1971–80 | 890 | 780 | 725 | 698 |
| 1971–86 | 1108 | 936 | 846 | 804 |
| 1971–91 | 4359 | 3581 | 3109 | 2872 |

*Note* Costs are discounted at 10 per cent.

*Source* BTCE estimates.

TABLE 6.7 MARGINAL COSTS FOR HIGH COST SCENARIO

*($1995–96/tonne)*

| *Intensity* | *2000* | *2005* | *2010* | *2015* |
|---|---|---|---|---|
| 1971–72 | 968 | 856 | 800 | 772 |
| 1971–75 | 1255 | 1110 | 1037 | 1001 |
| 1971–80 | 1661 | 1456 | 1353 | 1303 |
| 1971–86 | 2082 | 1758 | 1590 | 1511 |
| 1971–91 | 7857 | 6455 | 5603 | 5176 |

*Note* Costs are discounted at 10 per cent.

*Source* BTCE estimates.

The medium cost (most likely) scenario was also tested for sensitivity to the discount rate. Tables 6.8 and 6.9 show marginal costs at discount rates of 5 and 15 per cent respectively.

TABLE 6.8 MARGINAL COSTS AT 5 PER CENT DISCOUNT RATE
($1995–96/tonne)

| Intensity | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|
| 1971–72 | 1040 | 971 | 931 | 910 |
| 1971–75 | 1348 | 1259 | 1208 | 1181 |
| 1971–80 | 1793 | 1666 | 1595 | 1557 |
| 1971–86 | 2263 | 2062 | 1945 | 1883 |
| 1971–91 | 8557 | 7690 | 7092 | 6755 |

*Source* BTCE estimates.

TABLE 6.9 MARGINAL COSTS AT 15 PER CENT DISCOUNT RATE
($1995–96/tonne)

| Intensity | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|
| 1971–72 | 907 | 769 | 705 | 676 |
| 1971–75 | 1176 | 997 | 914 | 877 |
| 1971–80 | 1551 | 1296 | 1181 | 1130 |
| 1971–86 | 1930 | 1531 | 1345 | 1264 |
| 1971–91 | 7270 | 5543 | 4608 | 4178 |

*Source* BTCE estimates.

## EQUITY ISSUES

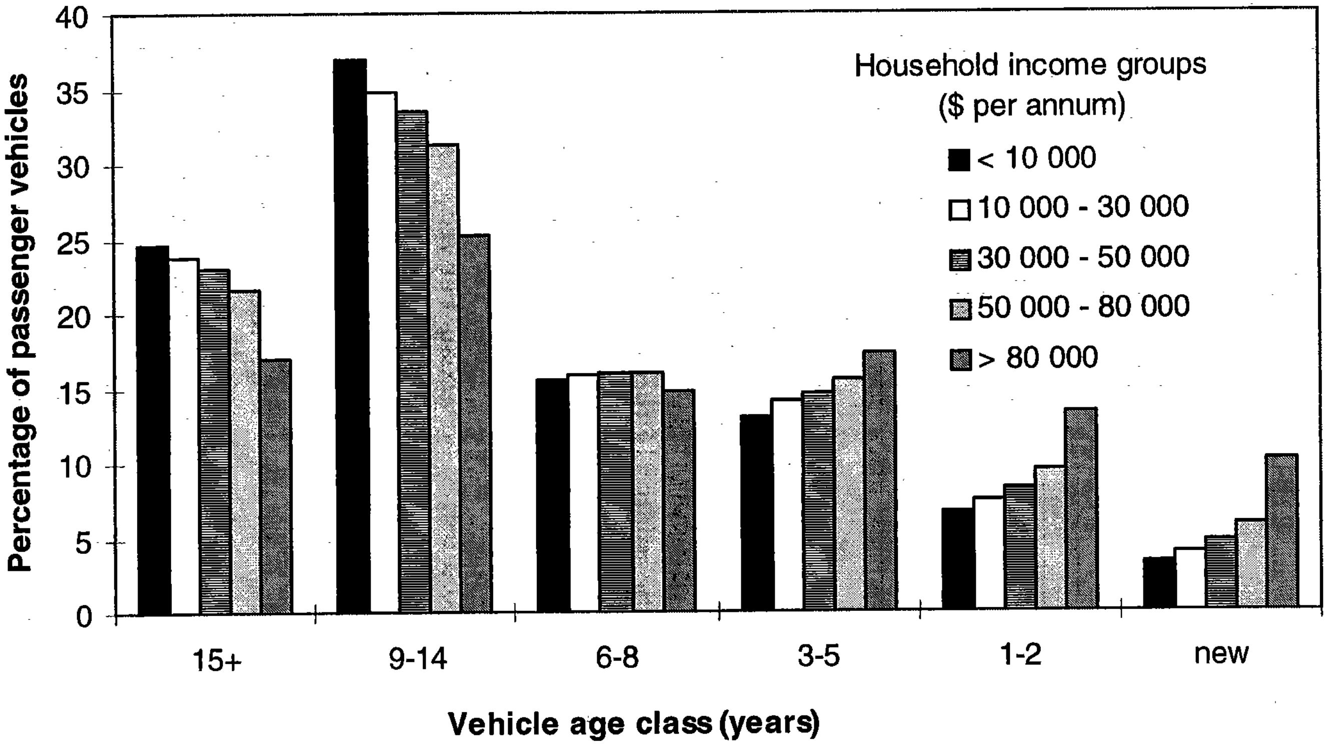
Compulsory tuning would impose costs on all vehicle owners unless it were targeted at vehicles of particular classes or vintages. The results of this analysis suggest that it would be relatively more cost-effective to target older vehicles. Figure 6.5, which shows the proportion of vehicles by age owned by different income groups in Australia, provides an indication of possible welfare effects of compulsory tuning.

Although a fairly marked difference exists 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 the graph would include the probably older additional (or second) vehicles of high income households, exaggerating the disparities between the proportions of vehicles owned by high and low income groups.

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 scrappage of vehicles that do not warrant the additional expense.

FIGURE 6.5 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

Compulsory tuning would probably provide some private benefits to motorists through better vehicle performance and lower fuel consumption. But motorists who are competent in tuning engines themselves and who tune them regularly would incur costs for professional tuning. Unless exemptions were provided for them, such as for owners of vintage cars (which make a very small contribution to emissions due to low distances travelled), some minor inequities could arise.

...AT A GLANCE

## ACCELERATED SCRAPPAGE OF OLDER CARS

Reductions in greenhouse gas emissions could be achieved through the targeted scrappage of older, fuel-inefficient, high emission cars. Their replacement with new vehicles would reduce fuel use, and produce less emissions.

## KEY FEATURES

- Cars that have high emissions of non-$CO_2$ gases, such as CO, and $NO_X$, also tend to have somewhat higher fuel consumption. A small number of cars in the fleet is also responsible for a disproportionate share of pollutant emissions. If these vehicles could be identified, the government could offer to buy and scrap them. The higher the government offer price, the greater the number of vehicles likely to be scrapped.
- It is assumed that inexpensive remote sensing of tailpipe emissions is used to identify gross polluting vehicles.
- Noticeable reductions in greenhouse gas emissions are achievable at medium cost (a maximum of over 20 million tonnes of cumulative reduction in $CO_2$ equivalents by 2015).

FIGURE 7.1 VEHICLE SCRAPPAGE: MARGINAL COSTS—2000

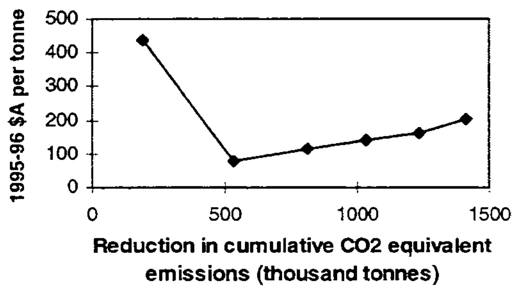



FIGURE 7.2 VEHICLE SCRAPPAGE: MARGINAL COSTS—2005

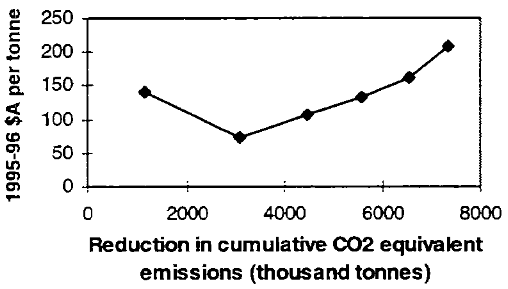



FIGURE 7.3 VEHICLE SCRAPPAGE: MARGINAL COSTS—2010

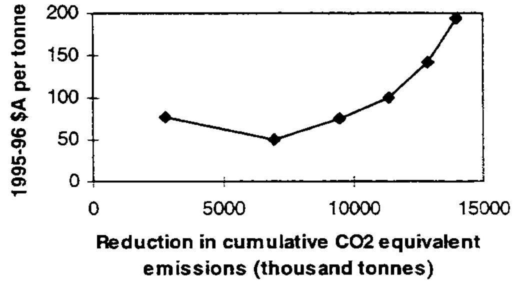
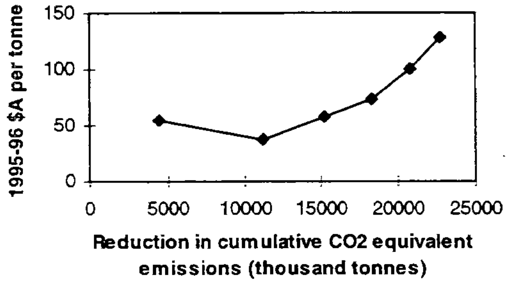



FIGURE 7.4 VEHICLE SCRAPPAGE: MARGINAL COSTS—2015




*Source* BTCE estimates.

# CHAPTER 7 ACCELERATED SCRAPPAGE OF OLDER CARS

## BACKGROUND

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

Under a 'cash for clunkers' policy, the government would annually identify cars which are particularly fuel inefficient with high emissions, make offers to buy these vehicles, and scrap those that it buys.

For the policy to operate, a way is needed of targeting inefficient cars (those using 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 is that all cars 13 years of age and older are eligible for purchase. On average, older cars are less expensive. In addition, as a group they tend to have generally higher fuel consumption and emissions of non- $CO_2$ greenhouse gases (FORS 1995).

Emission levels of non- $CO_2$ gases is the second target criterion. 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 1995). The emissions criterion takes advantage of this correlation to target particularly fuel- and emissions-inefficient vehicles.

It was assumed that the method of measuring emissions would involve a system such as remote road-side sensing of tailpipe emissions as cars drive by, coupled with photographic equipment to record licence numbers. Remote sensing is the cheapest method which identifies inefficient vehicles.

Existing remote sensing equipment has a fairly reliable level of measurement accuracy, but does give a proportion of false readings (Touche Ross 1995, pp. 158-161). As such, it is 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.

The number of clunkers removed from the road each year can be increased by raising the level of the offer price for targeted vehicles. This leads to increasing acceptances, albeit at a higher cost.

It is assumed that for every car sold to the government, a replacement vehicle is obtained (either through purchase of new vehicles or reduced scrappage of used ones). That is, it has been assumed that the desired fleet size for Australia as a whole is unaffected in any year.

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 is assumed to remain unchanged from base case projections.

There is evidence from the USA that, having accepted cash for their cars, some people then revert to using other family cars or public transport (Alberini et al. 1994a, pp. 71–72). This would mean a slightly higher saving in fuel. Thus the assumption of total replacement of the scrapped vehicles would tend to generate a conservative estimate of emissions reduction.

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

## METHODOLOGY

### Reductions in greenhouse gas emissions

Expected emissions reductions were determined using BTCE CARMOD, making use of the options for selection of high emission vehicles and for increasing the scrappage rate of older vehicles.

The CARMOD option for selecting high-emitters was run using the assumption that high emitting vehicles had emission rates of non-$CO_2$ gases three times that of an average vehicle of the same age. Similarly, fuel use by the high emitters was assumed to be 20 per cent greater than the average for the same vintage of vehicles.

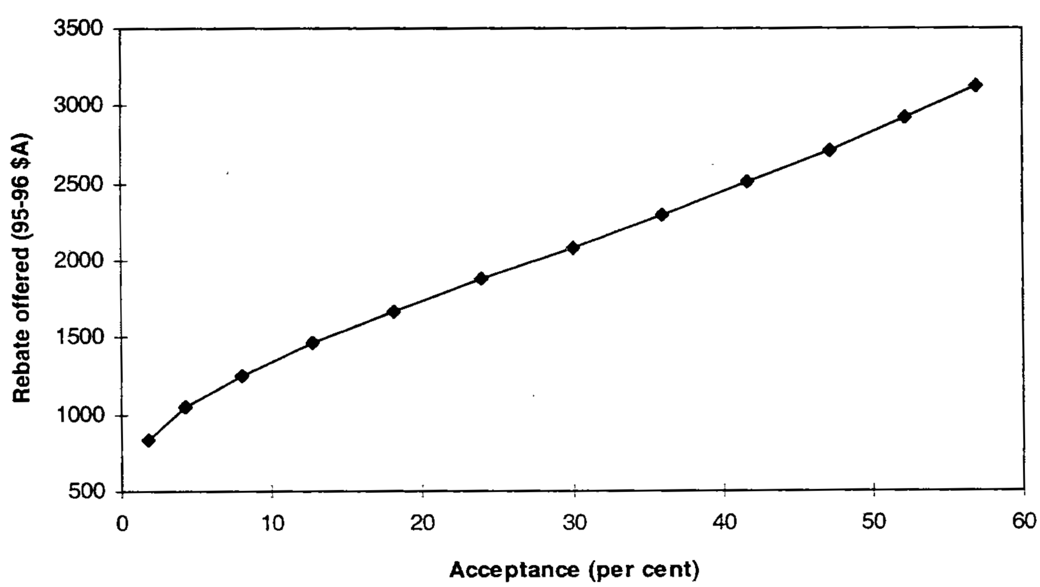
Numbers of vehicles scrapped under the policy were assumed to increase as the offer price increased. The assumed relationship between offer price and scrappage (acceptance) is shown in table 7.1 and figure 7.5. It was specified by drawing on data from a USA 'cash for clunkers' program (Alberini et al. 1994a, p. 59, Alberini et al. 1994b, 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 7.2 shows the offer price levels analysed in this study and the increased scrappage rates (as the per cent of the whole fleet) assumed to result from these offers.

TABLE 7.1 ACCEPTANCE BASED ON OFFER PRICE

| *Offer price ($95–96)* | *Acceptance (per cent of offers)* |
|---|---|
| 834 | 2 |
| 1,043 | 4 |
| 1,252 | 8 |
| 1,460 | 13 |
| 1,669 | 18 |
| 1,877 | 24 |
| 2,086 | 30 |
| 2,294 | 36 |
| 2,503 | 42 |
| 2,712 | 47 |
| 2,920 | 52 |
| 3,129 | 57 |

*Source* BTCE estimates based on Alberini et al. 1994a.

FIGURE 7.5 SCRAPPAGE ACCEPTANCE BASED ON OFFER PRICE




*Source* BTCE estimates.

TABLE 7.2 OFFER PRICES AND SCRAPPAGE RATES

| Offer price ($95–96) | Acceptance (per cent of offers) | Extra scrappage (per cent of total fleet) |
|---|---|---|
| 893 | 2.5 | 0.2 |
| 1 082 | 5.0 | 0.4 |
| 1 223 | 7.5 | 0.6 |
| 1 338 | 10.0 | 0.7 |
| 1 447 | 12.5 | 0.9 |
| 1 545 | 15.0 | 1.0 |

*Source* BTCE estimates.

In the simulation, it was necessary to use 10 year blocks of vehicle ages, and therefore the possible emissions reductions might be understated to some extent, as new target vintages are not being added continuously. However balancing this, is the fact that the effectiveness of the policy depends on the number of clunkers still in the fleet and the degree to which they are worse than average. Both of these factors may decline in importance if the policy has been in place for some time.

Replacement vehicles come from two sources—purchases of new cars and reduced scrappage of used ones. As the level of subsidy and scrappage of clunkers increases, it is assumed that the proportion of replacement vehicles coming from new car purchases rises—from 4.5 per cent when 1 per cent of 13 year and older are scrapped, to 25 per cent when 6 per cent of the older cars are scrapped per year.

**Costs**

*Consumers* benefit from owning cars that use less petrol. Purchase 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 fleet fuel use, and this is costed at the estimated 1995–96 retail petrol price of 74.2 cents per litre as a saving to the consumer. Costs of replacement vehicles are balanced by the stream of benefits that the use of these vehicles are expected to generate over time.

Scrappage subsidies received from the government are a cost saving to consumers, but are partially balanced by the loss of the services of the car turned over for scrappage (assumed to be less than the average subsidy necessary to obtain the marginal acceptance of offer—see Alberini 1994a, p.31).

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

Government costs are in testing, administration and tax revenue changes. Remote sensing units are assumed to cost $200 000 each and to last five years (FORS pers. comm., 1995). Technicians to maintain them are 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, this policy would require 30 to 40 remote sensing units for Australia as a whole.

It is assumed that there is a once-off start-up cost of $2 million for setting up the administration of the program. Thereafter, government administration costs are calculated on the basis of $5 per test, and include all the processing of the tests, offers and purchases (Touche Ross 1995, p. 183).

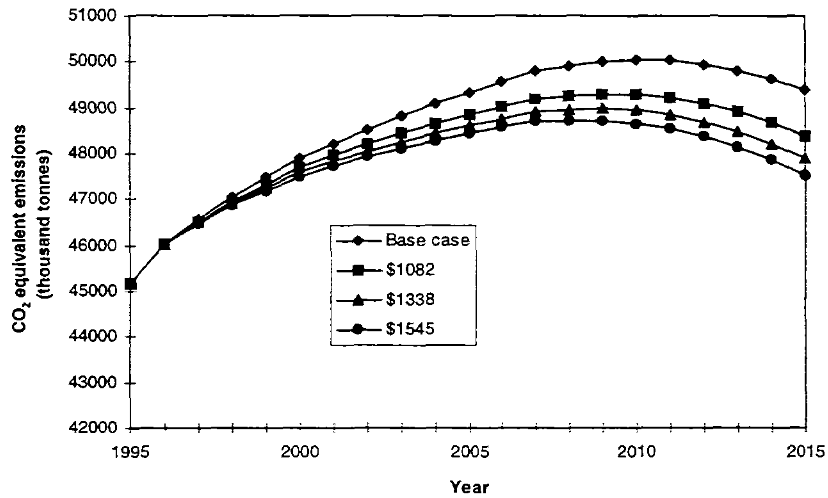
Government revenue changes come from several sources. There is a loss of fuel excise taxes and oil company profit taxes. There is also the value of payments made to purchase the cars (any residual scrappage value of the cars is ignored).

Externalities are mainly in the area of pollution reduction, through having newer, more fuel- and emissions-efficient cars replacing the most polluting older vehicles. Urban and non-urban rates of health benefits given in appendix III were used to value the reductions in pollutants estimated using BTCE CARMOD.

## RESULTS

The greenhouse benefits of the policy are limited to a 1 to 5 per cent reduction in cumulative emissions. There is a fairly quick reduction in $CO_2$ equivalent emissions through to 2005 and a consistent reduction over the base case thereafter (figure 7.6). Table 7.3 shows decreases in total greenhouse gas emissions as the offer price is raised.

FIGURE 7.6 EFFECT OF 'CASH FOR CLUNKERS' SCHEME ON EMISSIONS




*Source* BTCE estimates.

TABLE 7.3 DECREASE IN TOTAL CUMULATIVE GREENHOUSE GAS EMISSIONS OVER BASE CASE

*('000 tonnes cumulative $CO_2$ equivalent)*

| *Offer* | *Year* | | | |
|---|---|---|---|---|
| *price ($1995–96)* | *2000* | *2005* | *2010* | *2015* |
| $893 | 381 | 2342 | 5478 | 8834 |
| $1082 | 688 | 3860 | 8367 | 13446 |
| $1223 | 930 | 5049 | 10502 | 16857 |
| $1338 | 1136 | 6092 | 12235 | 19671 |
| $1447 | 1330 | 7000 | 13510 | 21845 |
| $1545 | 1490 | 7727 | 14452 | 23583 |

*Source* BTCE estimates.

Letting the policy operate from 1996 to 2015, the marginal cost per tonne of cumulative CO2 equivalent reduced is $55 per tonne at its minimum, rising to $128 per tonne (figure 7.4).

The cash for clunkers policy relies on reductions of older vehicles, and this can be accomplished only relatively slowly. Cost levels per tonne of reduction are generally higher at earlier dates of assessment than in 2015 (figures 7.1 to 7.3).

## Sensitivity testing

The results were tested for sensitivity to the discount rate. Table 7.4 and figure 7.7 show the marginal costs with the base case discount rate of 10 per cent, and two alternative rates of 5 and 15 per cent. At higher discount rates the net present value of the cost stream is reduced, and vice versa.

TABLE 7.4 SENSITIVITY ANALYSIS ON MARGINAL COSTS TO 2015 OF VARIATIONS IN THE DISCOUNT RATE

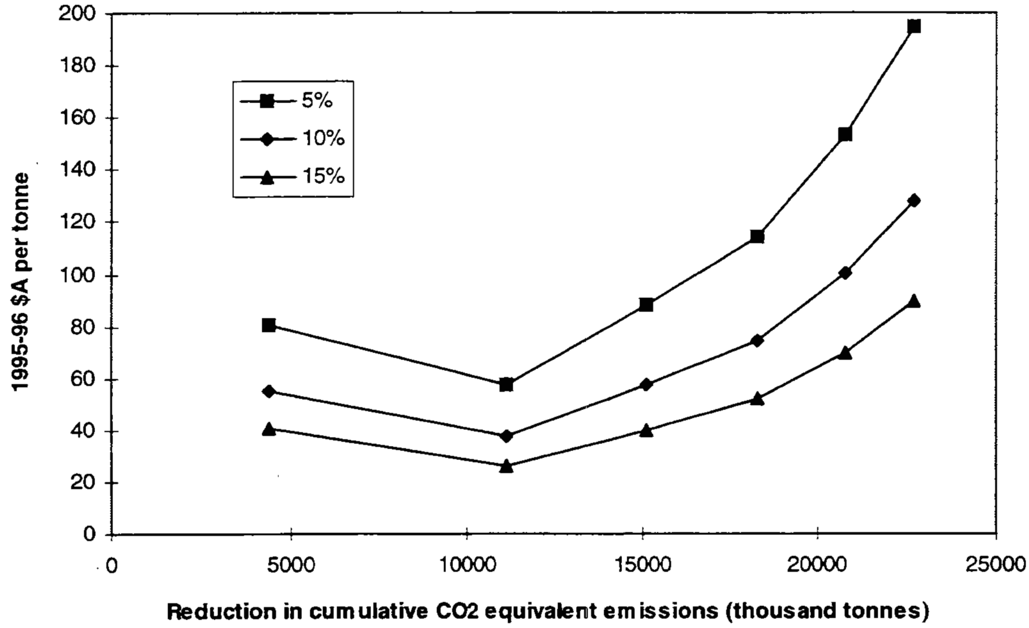
*($1995–96 per tonne of cumulative $CO_2$ equivalent emissions)*

| *Offer* | *Discount rate (per cent)* | | |
|---|---|---|---|
| *price ($1995–96)* | *5* | *10* | *15* |
| $ 893 | 80 | 55 | 41 |
| $1082 | 57 | 37 | 26 |
| $1223 | 88 | 57 | 40 |
| $1338 | 114 | 74 | 52 |
| $1447 | 154 | 100 | 70 |
| $1545 | 195 | 128 | 90 |

*Source* BTCE estimates.

A second sensitivity test was done by varying the offer price assumed to correspond to the acceptance level. In one scenario, the offer price was halved—for example it was assumed that an offer price of $446 (rather than $893) would lead to an acceptance level of 2.5 per cent. In the second scenario, it was assumed that offer prices would need to be half again as large as the original analysis—for example an acceptance level of 2.5 per cent would require an offer of $1340. Table 7.5 shows how the marginal costs change with different assumptions about offer prices. Marginal costs decrease with lower offer prices and increase with higher offer prices. However, the marginal cost changes are not exactly in proportion to the offer prices due to the influence of the other costs.

FIGURE 7.7 MARGINAL COSTS TO 2015 AT 5%, 10% AND 15% DISCOUNT RATES




*Source* BTCE estimates.

TABLE 7.5 SENSITIVITY ANALYSIS ON MARGINAL COSTS TO 2015 OF VARIATIONS IN ACCEPTANCES

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

| | *Offer price $1995–96* | | |
|---|---|---|---|
| *Acceptance level (per cent)* | *Half normal* | *Normal* | *One and a half normal* |
| 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.

## EQUITY ISSUES

Tables 7.6 to 7.9 show the distribution of total costs between consumers, producers, governments and externalities in the 'snapshot' years.

People selling old cars generally benefit, in that they obtain a surplus over their valuations of them (Alberini 1994a, p.31). Generally, they would tend to be people on lower incomes. The relationship between age of vehicle driven and income of the owners is shown in figure 6.5.

However, people who accept offers for their vehicles, as well as other consumers, would be likely to face somewhat higher prices in the markets for older replacement cars, due to a reduced supply of cheaper older vehicles.

TABLE 7.6 COMPOSITION OF TOTAL COSTS IN 2015

*($1995–96 millions)*

| *Offer price* | *$893* | *$1082* | *$1223* | *$1338* | *$1447* | $1545 |
|---|---|---|---|---|---|---|
| *Sector* | | | | | | |
| 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 | 1253.8 | 1541.7 | 1838.1 |
| Externalities | -0.1 | -0.2 | -0.2 | -0.3 | -0.3 | -0.3 |
| **Total** | **451.2** | **581.6** | **716.8** | **850.4** | **979.0** | **1103.0** |

*Source* BTCE estimates.

TABLE 7.7 COMPOSITION OF TOTAL COSTS IN 2010

*($1995–96 millions)*

| *Offer price* | *$893* | *$1082* | *$1223* | *$1338* | *$1447* | $1545 |
|---|---|---|---|---|---|---|
| *Sector* | | | | | | |
| Consumer | -52.1 | -119.8 | -209.3 | -315.7 | -442.6 | -581.1 |
| Producer | 0.5 | 1.1 | 1.9 | 3.0 | 4.4 | 5.8 |
| Government | 448.3 | 628.8 | 835.9 | 1059.1 | 1298.5 | 1545.8 |
| Externalities | -0.1 | -0.1 | -0.2 | -0.2 | -0.2 | -0.3 |
| **Total** | **396.7** | **510.0** | **628.4** | **746.3** | **860.0** | **969.3** |

*Source* BTCE estimates.

TABLE 7.8 COMPOSITION OF TOTAL COSTS IN 2005

*($1995–96 millions)*

| *Offer price* | *$893* | *$1082* | *$1223* | *$1338* | *$1447* | $1545 |
|---|---|---|---|---|---|---|
| *Sector* | | | | | | |
| Consumer | -36.8 | -88.1 | -154.2 | -232.8 | -326.9 | -431.7 |
| Producer | 0.3 | 0.7 | 1.3 | 2.1 | 3.0 | 4.0 |
| Government | 352.3 | 494.4 | 658.7 | 837.5 | 1031.4 | 1234.2 |
| Externalities | 0.0 | -0.1 | -0.1 | -0.1 | -0.2 | -0.2 |
| **Total** | **315.7** | **406.9** | **505.6** | **606.7** | **707.4** | **806.3** |

*Source* BTCE estimates.

TABLE 7.9 COMPOSITION OF TOTAL COSTS IN 2000

*($1995–96 millions)*

| *Offer price* | *$893* | *$1082* | *$1223* | *$1338* | *$1447* | $1545 |
|---|---|---|---|---|---|---|
| *Sector* | | | | | | |
| Consumer | -4.9 | -13.3 | -24.5 | -38.0 | -54.4 | -72.9 |
| Producer | 0.0 | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 |
| Government | 172 | 203.0 | 238.7 | 277.6 | 319.8 | 364.1 |
| Externalities | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.1 |
| **Total** | **167.2** | **189.7** | **214.3** | **239.7** | **265.6** | **219.6** |

*Source* BTCE estimates.

As a group, consumers also save on fuel costs, as the numbers of fuel inefficient, high emission vehicles are reduced from what they would otherwise be.

Governments (taxpayers) bear much of the cost of the policy. There are reductions in the amount of fuel excise collected. In addition, there is the cost of subsidies for scrappage.

Oil companies (producers) have reduced profit as a result of lost sales.

The health benefits (externalities) are minor.

# CHAPTER 8 CONCLUSIONS

The development of BTCE CARMOD allows improved accuracy in the simulation of the dynamics of the Australian car fleet. In turn, this produces more realistic long-term projections of greenhouse gas and noxious emissions from cars. The base case projections (that is, under business-as-usual assumptions) show that greenhouse gas emissions from cars are expected to increase by about 10 per cent between 1995 and 2015 (in $CO_2$ equivalents). Noxious emissions should show a substantial decline (of about a quarter), especially if problems with catalyst failure are addressed.

Of the four possible greenhouse gas policy initiatives for passenger vehicles analysed in this working paper, the most promising is the accelerated introduction of fuel efficient technology in new cars, although it is critically dependent on assumptions about the costs of increasing fuel efficiency. The least promising from a greenhouse gas reduction point of view is compulsory tuning of passenger vehicle engines.

Extreme caution should be exercised in drawing prescriptive policy conclusions from the results presented in this working paper.

The four measures evaluated provide only a very partial picture of the scope for reducing greenhouse emissions in the transport sector. Other, more cost-effective options may well be available. Introduction of relatively more costly options would result in an unnecessary reduction in the community's welfare because of the greater economic costs involved.

Similarly, there is a danger that the availability of cost information (as presented in this working paper) regarding the transport sector may attract premature interest on the part of policy makers. Introduction of greenhouse abatement measures in the transport sector may be more expensive to the community than comparable measures in other sectors. Informed decisions can be taken only if information on marginal costs of abatement are available for alternative options in other areas of the economy, such as the energy generation or residential sectors.

# APPENDIX I CONVERSION FACTORS

## GLOBAL WARMING POTENTIALS (GWPs)

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, infra-red 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. This is done on the basis of the GWP for each gas. The GWP is an index, defined to be the warming effect over a given period (usually taken as 100 years) due to an emission of a particular gas, relative to that of an equal mass of $CO_2$.

Representative GWP values have been calculated for the main greenhouse gases by the Intergovernmental Panel on Climate Change (IPCC). Due to the varying lifetime of greenhouse gases, GWP figures depend on the assumed time period over which the effects of emissions are considered. The IPCC (1990, 1992, 1994) 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 1992 are presented in table I.1. Indirect GWP values were reported in IPCC 1990, and these are also presented in table I.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 (IPCC 1992, 1994).

The set of GWPs given in table I.1 does not therefore explicitly represent the current IPCC position, but is an indicative scenario for global warming based on various IPCC results. Though 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 on comparisons of alternative fuels. Rather than omit such analysis, the BTCE has used the 100 year GWP scenario given in table I.1, on the understanding that the results derived need to be suitably qualified. The values in table I.1 are identical to those used in BTCE Report 88 (BTCE 1995, p. 144).

TABLE I.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)* | *Global Warming Potential (GWP) Time horizon (years)* | | |
|---|---|---|---|---|---|
| | | | *20* | *100* | *500* |
| *Direct* | | | | | |
| $CO_2$ | 355 | 50 - 200 | 1 | 1 | 1 |
| $CH_4$[a] | 1.7 | 12–17 | 62 | 24.5 | 7.5 |
| $N_2O$ | 0.3 | 120 | 290 | 320 | 180 |
| CFC-12[b] | 0.0005 | 102 | 7900 | 8500 | 4200 |
| *Indirect (ozone precursors)* | | | | | |
| 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. CFC-12 is the main chlorofluorocarbon used in transport vehicle air conditioners.

*Sources* IPCC (1990, 1992, 1994), IEA (1993).

The analyses of marginal emission abatement costs (chapters 4 to 7 of the working paper) are based on cumulative emission reductions over the period 1996 to 2015, weighted by the respective GWP values (in table I.1). The GWPs used average the radiative effects of emissions over 100 years, and take account of the differing amounts of time that the various gases emitted reside in the atmosphere. The implementation costs of abatement measures are accounted for dynamically, with costs scheduled to occur in future years discounted appropriately (at a discount rate of 10 per cent).

Studies dealing with policies for greenhouse abatement generally treat reductions of greenhouse gases equally, whether reductions occur in the near term or in the distant future. However, any reduction in current emissions of greenhouse gases means that future atmospheric concentration levels will be lower than they would otherwise have been. If higher concentrations cause economic damage, then the cumulative costs of the damage will also be lower.

Because the benefits of reducing greenhouse gases are not known with sufficient certainty, studies of abatement strategies are effectively limited to estimating their cost-effectiveness (costs incurred to achieve a target or physical level of reduction in emissions). That is, the 'benefits' in a benefit-cost ratio would be expressed in physical rather than monetary units. The analyses presented in this working paper are based on cumulative emission reductions over various periods, and do not take into account the exact timing of emission reductions. That is, the issue of whether an emission reduction made now is 'worth' more (from a global warming point of view) than an identical reduction in the future is not addressed.

## ENERGY DENSITIES

For converting fuel consumption figures (in litres) into estimates of full combustion $CO_2$ emissions, the factors given in table I.2 are used in the model.

TABLE I.2 $CO_2$ EMISSION FACTORS AND ENERGY DENSITIES BY FUEL TYPE

| *Fuel type* | *$CO_2$ emission factor (g/MJ)* | *Energy density (MJ/L)* |
|---|---|---|
| Automotive gasoline | 66.0 | 34.2 |
| Automotive diesel oil | 69.7 | 38.6 |
| Liquefied petroleum gas | 59.4 | 25.7 |
| Natural gas[a] | 51.3 | .. |

.. not applicable

a. The energy density of natural gas is around 39 megajoules per cubic metre.

*Notes* 1. Values are expressed in gross calorific terms.

2. Figures for automotive gasoline refer to both leaded and unleaded forms.

*Sources* ADIPG (1991), NGGIC (1994a), Bush et al. (1993).

# APPENDIX II CARMOD DATA TABLES AND PROJECTIONS

TABLE II.1 PASSENGER CAR FLEET CHARACTERISTICS

| *Year* | *VKT (billion km)* | *Australian population (millions)* | *Vehicles per thousand persons* | *Number of vehicles ('000)* | *Average fuel intensity (litres/100km)*[a] |
|---|---|---|---|---|---|
| 1971 | 63.8 | 13.07 | 305.8 | 3997 | 12.28 |
| 1972 | 66.1 | 13.30 | 317.4 | 4222 | 12.32 |
| 1973 | 68.1 | 13.51 | 322.8 | 4362 | 12.43 |
| 1974 | 72.6 | 13.72 | 335.6 | 4604 | 12.43 |
| 1975 | 76.8 | 13.89 | 350.5 | 4869 | 12.44 |
| 1976 | 79.0 | 14.03 | 364.1 | 5108 | 12.56 |
| 1977 | 82.7 | 14.19 | 372.0 | 5278 | 12.59 |
| 1978 | 85.9 | 14.36 | 380.4 | 5462 | 12.57 |
| 1979 | 87.7 | 14.52 | 389.3 | 5652 | 12.69 |
| 1980 | 88.8 | 14.69 | 394.9 | 5801 | 12.61 |
| 1981 | 90.3 | 14.92 | 403.6 | 6022 | 12.56 |
| 1982 | 95.7 | 15.18 | 415.6 | 6308 | 12.38 |
| 1983 | 96.2 | 15.39 | 421.0 | 6480 | 12.27 |
| 1984 | 100.6 | 15.58 | 429.0 | 6683 | 12.17 |
| 1985 | 105.7 | 15.79 | 438.6 | 6926 | 12.07 |
| 1986 | 109.5 | 16.02 | 443.6 | 7106 | 12.02 |
| 1987 | 112.3 | 16.26 | 444.5 | 7227 | 11.92 |
| 1988 | 116.8 | 16.52 | 446.8 | 7382 | 11.83 |
| 1989 | 121.7 | 16.81 | 450.5 | 7574 | 11.91 |
| 1990 | 124.6 | 17.07 | 456.8 | 7797 | 12.00 |
| 1991 | 122.3 | 17.28 | 463.6 | 8012 | 12.23 |
| 1992 | 124.3 | 17.48 | 465.8 | 8143 | 12.20 |
| 1993 | 126.4 | 17.67 | 468.6 | 8280 | 12.17 |
| 1994 | 130.4 | 17.84 | 471.1 | 8404 | 12.13 |
| 1995 | 133.0 | 18.02 | 476.0 | 8579 | 12.08 |
| 1996 | 135.8 | 18.21 | 481.1 | 8760 | 12.10 |
| 1997 | 138.0 | 18.40 | 483.9 | 8902 | 12.13 |
| 1998 | 140.2 | 18.59 | 486.5 | 9043 | 12.14 |
| 1999 | 142.3 | 18.78 | 488.9 | 9182 | 12.13 |
| 2000 | 144.5 | 18.98 | 491.1 | 9320 | 12.11 |
| 2001 | 146.5 | 19.17 | 493.2 | 9454 | 12.08 |
| 2002 | 148.6 | 19.36 | 495.0 | 9584 | 12.03 |
| 2003 | 150.5 | 19.55 | 496.8 | 9711 | 11.99 |
| 2004 | 152.4 | 19.73 | 498.4 | 9834 | 11.94 |
| 2005 | 154.3 | 19.92 | 499.8 | 9955 | 11.89 |
| 2006 | 156.1 | 20.10 | 501.2 | 10072 | 11.83 |
| 2007 | 157.9 | 20.27 | 502.4 | 10185 | 11.77 |
| 2008 | 159.6 | 20.45 | 503.5 | 10295 | 11.69 |
| 2009 | 161.2 | 20.62 | 504.6 | 10403 | 11.60 |
| 2010 | 162.9 | 20.79 | 505.5 | 10508 | 11.51 |
| 2011 | 164.5 | 20.95 | 506.4 | 10611 | 11.40 |
| 2012 | 166.0 | 21.12 | 507.2 | 10711 | 11.28 |
| 2013 | 167.5 | 21.28 | 508.0 | 10810 | 11.16 |
| 2014 | 169.1 | 21.44 | 508.7 | 10907 | 11.02 |
| 2015 | 170.5 | 21.60 | 509.3 | 11001 | 10.87 |

a. Litres of petrol equivalent (in energy terms) to allow for LPG, diesel and natural gas use.

*Sources* ABS (1995a, 1994a, 1994b, 1994c, 1993a), Cosgrove & Gargett (1992), BTCE (1995), BTCE estimates.

TABLE II.2 FLEET AND NEW VEHICLE CHARACTERISTICS

| *Year* | *New vehicle registrations ('000)* | *New vehicle fuel intensity (litres/100km)* | *Average annual fleet utilisation ('000 km)* | *Number of vehicles scrapped ('000)* |
|---|---|---|---|---|
| 1971 | 417.2 | 12.60 | 15.96 | 139.5 |
| 1972 | 412.5 | 12.50 | 15.66 | 187.6 |
| 1973 | 429.7 | 12.60 | 15.61 | 290.4 |
| 1974 | 465.0 | 12.49 | 15.77 | 222.6 |
| 1975 | 502.7 | 12.28 | 15.78 | 238.2 |
| 1976 | 454.6 | 13.00 | 15.48 | 215.3 |
| 1977 | 447.1 | 12.95 | 15.67 | 276.9 |
| 1978 | 432.4 | 12.90 | 15.72 | 248.3 |
| 1979 | 463.5 | 12.60 | 15.52 | 273.6 |
| 1980 | 452.0 | 11.94 | 15.30 | 303.5 |
| 1981 | 456.6 | 12.01 | 15.05 | 235.6 |
| 1982 | 455.5 | 11.74 | 15.23 | 169.0 |
| 1983 | 426.4 | 11.30 | 14.91 | 255.0 |
| 1984 | 428.7 | 11.30 | 15.13 | 225.0 |
| 1985 | 483.2 | 11.36 | 15.28 | 240.4 |
| 1986 | 450.9 | 11.40 | 15.40 | 270.8 |
| 1987 | 367.1 | 11.20 | 15.55 | 245.9 |
| 1988 | 384.2 | 10.90 | 15.82 | 229.8 |
| 1989 | 447.9 | 10.81 | 16.07 | 255.8 |
| 1990 | 492.2 | 10.53 | 15.98 | 268.7 |
| 1991 | 440.8 | 10.41 | 15.26 | 226.2 |
| 1992 | 437.0 | 10.50 | 15.27 | 305.9 |
| 1993 | 449.8 | 10.50 | 15.27 | 312.6 |
| 1994 | 476.0 | 10.44 | 15.51 | 352.0 |
| 1995 | 514.7 | 10.38 | 15.50 | 340.0 |
| 1996 | 528.1 | 10.25 | 15.50 | 346.6 |
| 1997 | 494.6 | 10.12 | 15.50 | 352.6 |
| 1998 | 499.8 | 9.98 | 15.50 | 359.2 |
| 1999 | 505.3 | 9.85 | 15.50 | 366.4 |
| 2000 | 512.4 | 9.71 | 15.50 | 374.6 |
| 2001 | 518.3 | 9.63 | 15.50 | 383.9 |
| 2002 | 521.1 | 9.54 | 15.50 | 391.1 |
| 2003 | 525.3 | 9.45 | 15.50 | 398.4 |
| 2004 | 529.1 | 9.36 | 15.50 | 405.8 |
| 2005 | 533.3 | 9.27 | 15.50 | 413.0 |
| 2006 | 537.0 | 9.09 | 15.50 | 419.9 |
| 2007 | 540.3 | 8.91 | 15.50 | 427.1 |
| 2008 | 544.0 | 8.73 | 15.50 | 433.8 |
| 2009 | 548.3 | 8.56 | 15.50 | 440.1 |
| 2010 | 552.7 | 8.38 | 15.50 | 447.5 |
| 2011 | 558.0 | 8.17 | 15.50 | 455.6 |
| 2012 | 564.4 | 7.96 | 15.50 | 463.8 |
| 2013 | 569.4 | 7.75 | 15.50 | 471.0 |
| 2014 | 575.2 | 7.54 | 15.50 | 478.4 |
| 2015 | 580.7 | 7.33 | 15.50 | 485.8 |

*Sources* ABS (1995a, 1994a, 1994b, 1994c, 1993a), Cosgrove & Gargett (1992), BTCE (1995), BTCE estimates.

TABLE II.3 PASSENGER CAR FUEL CONSUMPTION

| | Fuel consumption (Petajoules) | | | | |
|---|---|---|---|---|---|
| *Year* | *Petrol* | *Diesel* | *LPG* | *NG* | *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 |

NG Natural gas

LPG liquefied petroleum gas

*Note* Petajoules (PJ) equal $10^{15}$ joules (for energy conversion factors see appendix II).

*Sources* ABS (1993a and earlier), Bush et al. (1993), BTCE(1995), BTCE estimates.

TABLE II.4 PASSENGER CAR EMISSION PROJECTIONS

| | Emission rate (g/km) | | | | | | |
|---|---|---|---|---|---|---|---|
| *Year* | *$CO_2$* | *CO* | *$NO_x$* | *$CH_4$* | *$N_2O$* | *NMVOCs* | *$CO_2$ equivalent* |
| 1991 | 33334 | 3085 | 208.3 | 16.6 | 1.5 | 502.6 | 42978 |
| 1992 | 33804 | 3079 | 211.7 | 16.2 | 1.6 | 493.0 | 43429 |
| 1993 | 34252 | 3039 | 211.9 | 15.6 | 1.7 | 480.3 | 43769 |
| 1994 | 35198 | 3030 | 215.2 | 15.3 | 1.9 | 474.3 | 44733 |
| 1995 | 35742 | 2978 | 215.6 | 14.8 | 2.1 | 463.8 | 45185 |
| 1996 | 36572 | 2934 | 215.5 | 14.3 | 2.3 | 463.0 | 46009 |
| 1997 | 37244 | 2872 | 214.7 | 13.7 | 2.4 | 453.2 | 46566 |
| 1998 | 37865 | 2803 | 213.6 | 13.2 | 2.6 | 442.3 | 47057 |
| 1999 | 38424 | 2739 | 212.5 | 12.7 | 2.7 | 432.0 | 47493 |
| 2000 | 38941 | 2675 | 211.4 | 12.3 | 2.8 | 422.5 | 47893 |
| 2001 | 39381 | 2609 | 211.2 | 11.9 | 3.0 | 413.0 | 48220 |
| 2002 | 39771 | 2555 | 211.2 | 11.4 | 3.1 | 404.9 | 48515 |
| 2003 | 40140 | 2506 | 211.2 | 11.1 | 3.2 | 398.0 | 48806 |
| 2004 | 40484 | 2461 | 211.1 | 10.9 | 3.3 | 391.9 | 49081 |
| 2005 | 40804 | 2418 | 211.0 | 10.7 | 3.4 | 386.4 | 49337 |
| 2006 | 41079 | 2384 | 209.7 | 10.5 | 3.4 | 382.5 | 49559 |
| 2007 | 41296 | 2368 | 208.7 | 10.0 | 3.7 | 380.8 | 49803 |
| 2008 | 41460 | 2342 | 207.4 | 10.0 | 3.7 | 378.2 | 49921 |
| 2009 | 41575 | 2323 | 206.2 | 10.1 | 3.7 | 376.6 | 50006 |
| 2010 | 41633 | 2309 | 205.0 | 10.2 | 3.8 | 376.0 | 50048 |
| 2011 | 41634 | 2290 | 204.9 | 10.4 | 3.8 | 374.8 | 50034 |
| 2012 | 41578 | 2270 | 204.9 | 10.7 | 3.8 | 373.3 | 49958 |
| 2013 | 41461 | 2252 | 205.1 | 10.7 | 3.8 | 372.0 | 49822 |
| 2014 | 41286 | 2236 | 205.4 | 11.2 | 3.9 | 370.7 | 49640 |
| 2015 | 41050 | 2219 | 205.5 | 11.9 | 3.9 | 369.5 | 49398 |

*Note* Gigagrams (Gg) equal $10^9$ grams.

*Source* BTCE estimates.

TABLE II.5 AVERAGE EMISSION RATES BY YEAR OF MANUFACTURE

| | Emission rate (g/km) | | | | | |
|---|---|---|---|---|---|---|
| | | | | | NMVOCs | |
| Year | $CH_4$ | $N_2O$ | $NO_x$ | CO | exhaust | evaporative |
| 1971 | 0.21 | 0.004 | 2.15 | 37.84 | 3.33 | 2.87 |
| 1972 | 0.21 | 0.004 | 2.15 | 37.84 | 3.33 | 2.87 |
| 1973 | 0.21 | 0.004 | 2.15 | 37.84 | 3.33 | 2.87 |
| 1974 | 0.21 | 0.004 | 2.15 | 37.84 | 3.33 | 2.87 |
| 1975 | 0.21 | 0.004 | 2.15 | 37.84 | 3.33 | 2.87 |
| 1976 | 0.18 | 0.004 | 1.87 | 37.15 | 2.88 | 2.40 |
| 1977 | 0.18 | 0.004 | 1.87 | 37.15 | 2.88 | 2.40 |
| 1978 | 0.18 | 0.004 | 1.87 | 37.15 | 2.88 | 2.40 |
| 1979 | 0.18 | 0.004 | 1.87 | 37.15 | 2.88 | 2.40 |
| 1980 | 0.18 | 0.004 | 1.87 | 37.15 | 2.88 | 2.40 |
| 1981 | 0.15 | 0.004 | 1.70 | 28.93 | 2.38 | 2.40 |
| 1982 | 0.15 | 0.004 | 1.70 | 28.93 | 2.38 | 2.40 |
| 1983 | 0.15 | 0.004 | 1.70 | 28.93 | 2.38 | 2.40 |
| 1984 | 0.15 | 0.004 | 1.70 | 28.93 | 2.38 | 2.40 |
| 1985 | 0.15 | 0.004 | 1.70 | 28.93 | 2.38 | 2.40 |
| 1986 | 0.10 | 0.025 | 1.23 | 7.81 | 0.50 | 1.23 |
| 1987 | 0.10 | 0.025 | 1.23 | 7.81 | 0.50 | 1.23 |
| 1988 | 0.10 | 0.025 | 1.23 | 7.81 | 0.50 | 1.23 |
| 1989 | 0.10 | 0.025 | 1.23 | 7.81 | 0.50 | 1.23 |
| 1990 | 0.10 | 0.025 | 1.23 | 7.81 | 0.50 | 1.23 |
| 1991 | 0.10 | 0.025 | 1.23 | 7.81 | 0.50 | 1.23 |
| 1992 | 0.06 | 0.025 | 0.70 | 4.50 | 0.32 | 1.23 |
| 1993 | 0.06 | 0.025 | 0.70 | 4.50 | 0.32 | 1.23 |
| 1994 | 0.06 | 0.025 | 0.70 | 4.50 | 0.32 | 1.23 |
| 1995 | 0.06 | 0.025 | 0.70 | 4.50 | 0.32 | 1.23 |
| 1996 | 0.06 | 0.025 | 0.70 | 4.50 | 0.32 | 1.23 |
| 1997 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 1998 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 1999 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2000 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2001 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2002 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2003 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2004 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2005 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2006 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2007 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2008 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2009 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2010 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2011 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2012 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2013 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2014 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |
| 2015 | 0.05 | 0.025 | 0.63 | 2.10 | 0.26 | 1.06 |

*Sources* Carnovale et al. (1991), EPA NSW (1995), Hoekman (1992), Weeks et al. (1993), BTCE (1995), BTCE estimates.

TABLE II.6 PASSENGER VEHICLE EXHAUST EMISSION RATES FOR STABLE DRIVING CONDITIONS

| | Emission rate (g/km) | | | | |
|---|---|---|---|---|---|
| *Year* | *$CH_4$* | *$N_2O$* | *$NO_x$* | *CO* | *NMVOCs* |
| 1971 | 0.15 | 0.004 | 1.87 | 27.02 | 2.38 |
| 1972 | 0.15 | 0.004 | 1.87 | 27.02 | 2.38 |
| 1973 | 0.15 | 0.004 | 1.87 | 27.02 | 2.38 |
| 1974 | 0.15 | 0.004 | 1.87 | 27.02 | 2.38 |
| 1975 | 0.15 | 0.004 | 1.87 | 27.02 | 2.38 |
| 1976 | 0.13 | 0.004 | 1.63 | 26.53 | 2.06 |
| 1977 | 0.13 | 0.004 | 1.63 | 26.53 | 2.06 |
| 1978 | 0.13 | 0.004 | 1.63 | 26.53 | 2.06 |
| 1979 | 0.13 | 0.004 | 1.63 | 26.53 | 2.06 |
| 1980 | 0.13 | 0.004 | 1.63 | 26.53 | 2.06 |
| 1981 | 0.11 | 0.004 | 1.48 | 20.66 | 1.70 |
| 1982 | 0.11 | 0.004 | 1.48 | 20.66 | 1.70 |
| 1983 | 0.11 | 0.004 | 1.48 | 20.66 | 1.70 |
| 1984 | 0.11 | 0.004 | 1.48 | 20.66 | 1.70 |
| 1985 | 0.11 | 0.004 | 1.48 | 20.66 | 1.70 |
| 1986 | 0.04 | 0.025 | 1.02 | 3.03 | 0.19 |
| 1987 | 0.04 | 0.025 | 1.02 | 3.03 | 0.19 |
| 1988 | 0.04 | 0.025 | 1.02 | 3.03 | 0.19 |
| 1989 | 0.04 | 0.025 | 1.02 | 3.03 | 0.19 |
| 1990 | 0.04 | 0.025 | 1.02 | 3.03 | 0.19 |
| 1991 | 0.04 | 0.025 | 1.02 | 3.03 | 0.19 |
| 1992 | 0.02 | 0.025 | 0.58 | 1.75 | 0.12 |
| 1993 | 0.02 | 0.025 | 0.58 | 1.75 | 0.12 |
| 1994 | 0.02 | 0.025 | 0.58 | 1.75 | 0.12 |
| 1995 | 0.02 | 0.025 | 0.58 | 1.75 | 0.12 |
| 1996 | 0.02 | 0.025 | 0.58 | 1.75 | 0.12 |
| 1997 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 1998 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 1999 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2000 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2001 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2002 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2003 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2004 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2005 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2006 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2007 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2008 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2009 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2010 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2011 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2012 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2013 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2014 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |
| 2015 | 0.02 | 0.025 | 0.52 | 0.81 | 0.10 |

*Note* Stable driving conditions refer to free-flowing traffic on arterial roads.

*Sources* Bendtsen & Thorsen (1994), Adena & Montesin (1988), Carnovale et al. (1991), EPA NSW (1995), Hoekman (1992), Weeks et al. (1993), BTCE (1995), BTCE estimates.

TABLE II.7 EXHAUST EMISSION RATES FOR CONGESTED DRIVING CONDITIONS

| | Emission rate (g/km) | | | | |
|---|---|---|---|---|---|
| *Year* | *$CH_4$* | *$N_2O$* | *$NO_x$* | *CO* | *NMVOCs* |
| 1971 | 0.22 | 0.004 | 2.81 | 40.53 | 3.57 |
| 1972 | 0.22 | 0.004 | 2.81 | 40.53 | 3.57 |
| 1973 | 0.22 | 0.004 | 2.81 | 40.53 | 3.57 |
| 1974 | 0.22 | 0.004 | 2.81 | 40.53 | 3.57 |
| 1975 | 0.22 | 0.004 | 2.81 | 40.53 | 3.57 |
| 1976 | 0.19 | 0.004 | 2.44 | 39.79 | 3.08 |
| 1977 | 0.19 | 0.004 | 2.44 | 39.79 | 3.08 |
| 1978 | 0.19 | 0.004 | 2.44 | 39.79 | 3.08 |
| 1979 | 0.19 | 0.004 | 2.44 | 39.79 | 3.08 |
| 1980 | 0.19 | 0.004 | 2.44 | 39.79 | 3.08 |
| 1981 | 0.16 | 0.004 | 2.22 | 30.98 | 2.55 |
| 1982 | 0.16 | 0.004 | 2.22 | 30.98 | 2.55 |
| 1983 | 0.16 | 0.004 | 2.22 | 30.98 | 2.55 |
| 1984 | 0.16 | 0.004 | 2.22 | 30.98 | 2.55 |
| 1985 | 0.16 | 0.004 | 2.22 | 30.98 | 2.55 |
| 1986 | 0.06 | 0.025 | 1.33 | 4.85 | 0.31 |
| 1987 | 0.06 | 0.025 | 1.33 | 4.85 | 0.31 |
| 1988 | 0.06 | 0.025 | 1.33 | 4.85 | 0.31 |
| 1989 | 0.06 | 0.025 | 1.33 | 4.85 | 0.31 |
| 1990 | 0.06 | 0.025 | 1.33 | 4.85 | 0.31 |
| 1991 | 0.06 | 0.025 | 1.33 | 4.85 | 0.31 |
| 1992 | 0.04 | 0.025 | 0.76 | 2.79 | 0.20 |
| 1993 | 0.04 | 0.025 | 0.76 | 2.79 | 0.20 |
| 1994 | 0.04 | 0.025 | 0.76 | 2.79 | 0.20 |
| 1995 | 0.04 | 0.025 | 0.76 | 2.79 | 0.20 |
| 1996 | 0.04 | 0.025 | 0.76 | 2.79 | 0.20 |
| 1997 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 1998 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 1999 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2000 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2001 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2002 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2003 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2004 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2005 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2006 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2007 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2008 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2009 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2010 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2011 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2012 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2013 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2014 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |
| 2015 | 0.03 | 0.025 | 0.68 | 1.30 | 0.16 |

*Note* Congested driving conditions refer to peak urban traffic.

*Sources* Bendtsen & Thorsen (1994), Adena & Montesin (1988), Carnovale et al. (1991), EPA NSW (1995), Hoekman (1992), Weeks et al. (1993), BTCE (1995), BTCE estimates.

TABLE II.8 EXHAUST EMISSION RATES FOR COLD START CONDITIONS

| | Emission rate (g/km) | | | | |
|---|---|---|---|---|---|
| *Year* | *$CH_4$* | *$N_2O$* | *$NO_x$* | *CO* | *NMVOCs* |
| 1971 | 0.52 | 0.004 | 1.98 | 94.56 | 8.32 |
| 1972 | 0.52 | 0.004 | 1.98 | 94.56 | 8.32 |
| 1973 | 0.52 | 0.004 | 1.98 | 94.56 | 8.32 |
| 1974 | 0.52 | 0.004 | 1.98 | 94.56 | 8.32 |
| 1975 | 0.52 | 0.004 | 1.98 | 94.56 | 8.32 |
| 1976 | 0.45 | 0.004 | 1.72 | 92.84 | 7.20 |
| 1977 | 0.45 | 0.004 | 1.72 | 92.84 | 7.20 |
| 1978 | 0.45 | 0.004 | 1.72 | 92.84 | 7.20 |
| 1979 | 0.45 | 0.004 | 1.72 | 92.84 | 7.20 |
| 1980 | 0.45 | 0.004 | 1.72 | 92.84 | 7.20 |
| 1981 | 0.37 | 0.004 | 1.57 | 72.30 | 5.95 |
| 1982 | 0.37 | 0.004 | 1.57 | 72.30 | 5.95 |
| 1983 | 0.37 | 0.004 | 1.57 | 72.30 | 5.95 |
| 1984 | 0.37 | 0.004 | 1.57 | 72.30 | 5.95 |
| 1985 | 0.37 | 0.004 | 1.57 | 72.30 | 5.95 |
| 1986 | 0.58 | 0.025 | 2.04 | 45.45 | 2.91 |
| 1987 | 0.58 | 0.025 | 2.04 | 45.45 | 2.91 |
| 1988 | 0.58 | 0.025 | 2.04 | 45.45 | 2.91 |
| 1989 | 0.58 | 0.025 | 2.04 | 45.45 | 2.91 |
| 1990 | 0.58 | 0.025 | 2.04 | 45.45 | 2.91 |
| 1991 | 0.58 | 0.025 | 2.04 | 45.45 | 2.91 |
| 1992 | 0.35 | 0.025 | 1.16 | 26.19 | 1.86 |
| 1993 | 0.35 | 0.025 | 1.16 | 26.19 | 1.86 |
| 1994 | 0.35 | 0.025 | 1.16 | 26.19 | 1.86 |
| 1995 | 0.35 | 0.025 | 1.16 | 26.19 | 1.86 |
| 1996 | 0.35 | 0.025 | 1.16 | 26.19 | 1.86 |
| 1997 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 1998 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 1999 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2000 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2001 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2002 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2003 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2004 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2005 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2006 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2007 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2008 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2009 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2010 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2011 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2012 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2013 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2014 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |
| 2015 | 0.29 | 0.025 | 1.05 | 12.22 | 1.51 |

*Note* Cold starts refer to running for less than 2.5 minutes after the car has been stopped for over two hours.

*Sources* Bendtsen & Thorsen (1994), Adena & Montesin (1988), Hoekman (1992), Weeks et al. (1993), BTCE (1995), BTCE estimates.

TABLE II.9 SCRAPPAGE BY AGE OF PASSENGER VEHICLE AND VINTAGE GROUP

| *Age of vehicle (years)* | *Scrappage rates (per cent of remaining stock scrapped over coming year)* | | | *Survival functions (proportion of original stock remaining)* | | |
|---|---|---|---|---|---|---|
| | Pre 1970 | 1971 to 1979 | Post 1980 | Pre 1970 | 1971 to 1979 | Post 1980 |
| 0 | 0.85 | 0.49 | 0.21 | 1.000 | 1.000 | 1.000 |
| 1 | 1.05 | 0.60 | 0.26 | 0.992 | 0.995 | 0.998 |
| 2 | 1.30 | 0.75 | 0.33 | 0.981 | 0.989 | 0.995 |
| 3 | 1.60 | 0.93 | 0.42 | 0.968 | 0.982 | 0.992 |
| 4 | 1.97 | 1.14 | 0.54 | 0.953 | 0.973 | 0.988 |
| 5 | 2.41 | 1.41 | 0.68 | 0.934 | 0.961 | 0.983 |
| 6 | 2.93 | 1.73 | 0.86 | 0.912 | 0.948 | 0.976 |
| 7 | 3.55 | 2.11 | 1.09 | 0.885 | 0.932 | 0.967 |
| 8 | 4.26 | 2.57 | 1.38 | 0.853 | 0.912 | 0.957 |
| 9 | 5.07 | 3.11 | 1.73 | 0.817 | 0.888 | 0.944 |
| 10 | 5.97 | 3.74 | 2.16 | 0.776 | 0.861 | 0.927 |
| 11 | 6.97 | 4.46 | 2.69 | 0.729 | 0.829 | 0.907 |
| 12 | 8.03 | 5.27 | 3.32 | 0.679 | 0.792 | 0.883 |
| 13 | 9.15 | 6.18 | 4.07 | 0.624 | 0.750 | 0.854 |
| 14 | 10.29 | 7.16 | 4.94 | 0.567 | 0.704 | 0.819 |
| 15 | 11.42 | 8.20 | 5.93 | 0.509 | 0.653 | 0.779 |
| 16 | 12.52 | 9.29 | 7.05 | 0.451 | 0.600 | 0.732 |
| 17 | 13.57 | 10.40 | 8.26 | 0.394 | 0.544 | 0.681 |
| 18 | 14.54 | 11.49 | 9.55 | 0.341 | 0.487 | 0.624 |
| 19 | 15.42 | 12.54 | 10.87 | 0.291 | 0.431 | 0.565 |
| 20 | 16.19 | 13.54 | 12.20 | 0.246 | 0.377 | 0.503 |
| 21 | 16.88 | 14.46 | 13.48 | 0.206 | 0.326 | 0.442 |
| 22 | 17.46 | 15.30 | 14.69 | 0.172 | 0.279 | 0.382 |
| 23 | 17.96 | 16.04 | 15.80 | 0.142 | 0.236 | 0.326 |
| 24 | 18.37 | 16.68 | 16.80 | 0.116 | 0.198 | 0.275 |
| 25 | 18.72 | 17.24 | 17.67 | 0.095 | 0.165 | 0.229 |
| 26 | 19.01 | 17.71 | 18.42 | 0.077 | 0.137 | 0.188 |
| 27 | 19.24 | 18.11 | 19.05 | 0.062 | 0.113 | 0.154 |
| 28 | 19.43 | 18.44 | 19.57 | 0.050 | 0.092 | 0.124 |
| 29 | 19.59 | 18.72 | 20.01 | 0.041 | 0.075 | 0.100 |
| 30 | 19.72 | 18.94 | 20.36 | 0.033 | 0.061 | 0.080 |
| 31 | 19.82 | 19.13 | 20.64 | 0.026 | 0.050 | 0.064 |
| 32 | 19.90 | 19.28 | 20.87 | 0.021 | 0.040 | 0.051 |
| 33 | 19.96 | 19.40 | 21.05 | 0.017 | 0.032 | 0.040 |
| 34 | 20.02 | 19.50 | 21.19 | 0.013 | 0.026 | 0.032 |
| 35 | 20.06 | 19.58 | 21.31 | 0.011 | 0.021 | 0.025 |

*Sources* ABS (1995a, 1994a, 1993a), CBCS (1973), Williams (1992), BTCE estimates.

TABLE II.10 PROJECTED FLEET STRUCTURE BY AGE OF PASSENGER VEHICLE

*('000 of vehicles)*

| *Age of vehicle (years)* | *Year* | | | | | |
|---|---|---|---|---|---|---|
| | *1991* | *1995* | *2000* | *2005* | *2010* | *2015* |
| 0 | 440.8 | 514.7 | 512.4 | 533.3 | 552.7 | 580.7 |
| 1 | 489.8 | 475.0 | 504.2 | 528.0 | 547.2 | 574.0 |
| 2 | 491.7 | 447.7 | 497.5 | 522.9 | 541.4 | 566.8 |
| 3 | 415.7 | 431.7 | 490.7 | 517.0 | 536.0 | 559.9 |
| 4 | 356.4 | 422.8 | 521.6 | 512.0 | 530.4 | 551.2 |
| 5 | 442.2 | 481.3 | 505.7 | 503.4 | 524.0 | 543.0 |
| 6 | 511.1 | 452.4 | 464.5 | 493.0 | 516.3 | 535.0 |
| 7 | 461.7 | 382.0 | 435.1 | 483.5 | 508.2 | 526.2 |
| 8 | 450.1 | 341.2 | 416.4 | 473.3 | 498.6 | 517.0 |
| 9 | 440.2 | 427.2 | 403.9 | 498.3 | 489.1 | 506.7 |
| 10 | 411.7 | 463.2 | 454.3 | 477.3 | 475.1 | 494.6 |
| 11 | 372.1 | 421.1 | 420.7 | 431.9 | 458.4 | 480.0 |
| 12 | 435.9 | 419.4 | 348.7 | 397.1 | 441.3 | 463.8 |
| 13 | 347.3 | 397.9 | 304.4 | 371.5 | 422.2 | 444.9 |
| 14 | 291.6 | 364.4 | 370.8 | 350.5 | 432.5 | 424.4 |
| 15 | 335.5 | 326.4 | 388.9 | 381.4 | 400.7 | 398.9 |
| 16 | 257.0 | 322.0 | 339.9 | 339.5 | 348.6 | 370.0 |
| 17 | 257.3 | 248.0 | 323.3 | 268.8 | 306.2 | 340.2 |
| 18 | 152.5 | 219.7 | 291.1 | 222.7 | 271.8 | 308.9 |
| 19 | 125.7 | 228.2 | 251.4 | 255.7 | 241.7 | 298.3 |
| 20 | 118.1 | 191.8 | 211.1 | 251.5 | 246.6 | 259.1 |
| Over 20 | 407.7 | 600.6 | 863.2 | 1141.9 | 1219.3 | 1257.7 |

*Sources* ABS (1995a, 1994a, 1993a), BTCE estimates.

TABLE II.11 PROJECTED FLEET UTILISATION BY AGE OF PASSENGER VEHICLE

*(millions of km travelled)*

| Age of vehicle (years) | Year | | | | | |
|---|---|---|---|---|---|---|
| | *1991* | *1995* | *2000* | *2005* | *2010* | *2015* |
| 0 | 5400 | 6305 | 6277 | 6533 | 6770 | 7113 |
| 1 | 11118 | 11284 | 12083 | 12741 | 13252 | 13927 |
| 2 | 9871 | 9408 | 10545 | 11160 | 11599 | 12163 |
| 3 | 8002 | 8702 | 9975 | 10584 | 11015 | 11526 |
| 4 | 6567 | 8154 | 10142 | 10027 | 10427 | 10854 |
| 5 | 7783 | 8865 | 9396 | 9422 | 9843 | 10219 |
| 6 | 8688 | 8051 | 8341 | 8917 | 9371 | 9729 |
| 7 | 7571 | 6561 | 7537 | 8432 | 8894 | 9226 |
| 8 | 7111 | 5648 | 6950 | 7951 | 8407 | 8733 |
| 9 | 6691 | 6796 | 6485 | 8049 | 7932 | 8233 |
| 10 | 6068 | 7142 | 7067 | 7476 | 7471 | 7790 |
| 11 | 5313 | 6293 | 6343 | 6559 | 6988 | 7330 |
| 12 | 6024 | 6065 | 5095 | 5842 | 6513 | 6856 |
| 13 | 4640 | 5561 | 4299 | 5279 | 6018 | 6351 |
| 14 | 3762 | 4918 | 5047 | 4807 | 5947 | 5849 |
| 15 | 4110 | 4184 | 5026 | 4965 | 5235 | 5222 |
| 16 | 2981 | 3906 | 4158 | 4182 | 4310 | 4582 |
| 17 | 2817 | 2842 | 3734 | 3130 | 3576 | 3979 |
| 18 | 1602 | 2414 | 3224 | 2488 | 3044 | 3464 |
| 19 | 1295 | 2460 | 2733 | 2800 | 2659 | 3282 |
| 20 | 1181 | 2009 | 2231 | 2674 | 2634 | 2772 |
| Over 20 | 3669 | 5406 | 7769 | 10277 | 10974 | 11319 |

*Sources* ABS (1995a, 1994a, 1993a), BTCE estimates.

TABLE II.12 PROJECTED FUEL INTENSITY BY AGE OF PASSENGER VEHICLE

*(litres per 100km)*

| Age of vehicle (years) | Year 1991 | 1995 | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|---|---|
| 0 | 10.51 | 10.38 | 9.71 | 9.27 | 8.38 | 7.33 |
| 1 | 11.16 | 10.76 | 10.14 | 9.64 | 8.81 | 7.76 |
| 2 | 11.67 | 11.13 | 10.58 | 10.02 | 9.26 | 8.21 |
| 3 | 11.77 | 11.45 | 11.03 | 10.40 | 9.72 | 8.67 |
| 4 | 12.10 | 11.77 | 11.48 | 10.78 | 10.19 | 9.15 |
| 5 | 12.31 | 12.35 | 11.84 | 11.07 | 10.57 | 9.55 |
| 6 | 12.27 | 12.77 | 12.11 | 11.42 | 10.86 | 9.92 |
| 7 | 12.20 | 12.74 | 12.39 | 11.78 | 11.15 | 10.31 |
| 8 | 12.20 | 12.85 | 12.50 | 12.04 | 11.35 | 10.61 |
| 9 | 12.68 | 12.96 | 12.61 | 12.30 | 11.55 | 10.91 |
| 10 | 12.79 | 12.69 | 13.00 | 12.46 | 11.66 | 11.13 |
| 11 | 12.66 | 12.41 | 13.22 | 12.53 | 11.82 | 11.23 |
| 12 | 12.92 | 12.18 | 12.83 | 12.48 | 11.86 | 11.23 |
| 13 | 13.00 | 12.43 | 12.70 | 12.35 | 11.90 | 11.22 |
| 14 | 13.08 | 12.41 | 12.57 | 12.24 | 11.93 | 11.20 |
| 15 | 13.18 | 12.15 | 12.50 | 12.48 | 11.96 | 11.19 |
| 16 | 12.67 | 12.39 | 12.30 | 12.55 | 11.91 | 11.23 |
| 17 | 12.60 | 12.47 | 12.17 | 12.18 | 11.85 | 11.26 |
| 18 | 13.00 | 12.54 | 12.33 | 12.05 | 11.72 | 11.29 |
| 19 | 12.70 | 12.63 | 12.61 | 12.02 | 11.60 | 11.32 |
| 20 | 13.00 | 12.27 | 12.54 | 11.98 | 11.96 | 11.46 |
| Over 20 | 12.80 | 12.69 | 12.53 | 12.31 | 12.14 | 11.85 |

*Sources* ABS (1995a, 1994a, 1993a), BTCE estimates.

TABLE II.13 PROJECTED PASSENGER VEHICLE FUEL CONSUMPTION BY VINTAGE

*(millions of litres)*

| *Age of vehicle (years)* | *Year* | | | | | |
|---|---|---|---|---|---|---|
| | *1991* | *1995* | *2000* | *2005* | *2010* | *2015* |
| 0 | 568 | 655 | 622 | 631 | 603 | 565 |
| 1 | 1241 | 1214 | 1251 | 1280 | 1241 | 1172 |
| 2 | 1152 | 1047 | 1139 | 1165 | 1142 | 1082 |
| 3 | 942 | 996 | 1123 | 1147 | 1138 | 1083 |
| 4 | 794 | 960 | 1189 | 1126 | 1129 | 1076 |
| 5 | 958 | 1095 | 1136 | 1087 | 1106 | 1058 |
| 6 | 1066 | 1029 | 1032 | 1061 | 1082 | 1047 |
| 7 | 924 | 836 | 954 | 1035 | 1054 | 1031 |
| 8 | 868 | 726 | 887 | 997 | 1014 | 1004 |
| 9 | 849 | 881 | 835 | 1032 | 974 | 974 |
| 10 | 776 | 906 | 938 | 971 | 926 | 940 |
| 11 | 673 | 781 | 856 | 856 | 878 | 893 |
| 12 | 778 | 739 | 667 | 759 | 821 | 834 |
| 13 | 603 | 691 | 557 | 679 | 761 | 772 |
| 14 | 492 | 610 | 648 | 613 | 754 | 710 |
| 15 | 542 | 508 | 641 | 646 | 666 | 633 |
| 16 | 378 | 484 | 522 | 547 | 545 | 558 |
| 17 | 355 | 354 | 464 | 397 | 450 | 486 |
| 18 | 208 | 303 | 406 | 312 | 379 | 424 |
| 19 | 164 | 311 | 352 | 351 | 328 | 403 |
| 20 | 154 | 246 | 286 | 334 | 335 | 344 |
| Over 20 | 470 | 686 | 994 | 1318 | 1416 | 1454 |

*Sources* ABS (1995a, 1994a, 1993a), BTCE estimates.

TABLE II.14 PROJECTED NON-$CO_2$ EMISSIONS BY AGE OF PASSENGER VEHICLE

*(Gg $CO_2$ equivalent)*

| *Age of vehicle (years)* | *Year* | | | | | |
|---|---|---|---|---|---|---|
| | *1991* | *1995* | *2000* | *2005* | *2010* | *2015* |
| 0 | 247 | 216 | 179 | 186 | 191 | 198 |
| 1 | 508 | 410 | 380 | 400 | 412 | 427 |
| 2 | 451 | 362 | 354 | 374 | 386 | 399 |
| 3 | 366 | 354 | 356 | 378 | 390 | 402 |
| 4 | 300 | 440 | 445 | 379 | 392 | 402 |
| 5 | 356 | 479 | 433 | 377 | 391 | 400 |
| 6 | 782 | 435 | 396 | 376 | 392 | 401 |
| 7 | 681 | 354 | 372 | 374 | 391 | 400 |
| 8 | 640 | 305 | 357 | 368 | 386 | 396 |
| 9 | 602 | 367 | 419 | 438 | 382 | 390 |
| 10 | 546 | 702 | 457 | 423 | 375 | 386 |
| 11 | 558 | 618 | 410 | 381 | 366 | 379 |
| 12 | 633 | 596 | 330 | 350 | 355 | 369 |
| 13 | 488 | 546 | 278 | 328 | 341 | 355 |
| 14 | 395 | 483 | 327 | 362 | 385 | 339 |
| 15 | 432 | 474 | 561 | 374 | 351 | 314 |
| 16 | 348 | 442 | 464 | 315 | 295 | 285 |
| 17 | 328 | 322 | 417 | 236 | 251 | 256 |
| 18 | 187 | 273 | 360 | 188 | 220 | 230 |
| 19 | 151 | 279 | 305 | 211 | 227 | 244 |
| 20 | 138 | 250 | 284 | 329 | 225 | 212 |
| Over 20 | 508 | 735 | 1068 | 1389 | 1308 | 1163 |

*Note* Gigagrams (Gg) equal $10^9$ grams.

*Source* BTCE estimates.

TABLE II.15 TOTAL PASSENGER VEHICLE EMISSION PROJECTIONS BY SECTOR

*(Gg $CO_2$ equivalent)*

| *Year* | *Sector* | |
|---|---|---|
| | *Urban* | *Non-urban* |
| 1992 | 31584 | 11845 |
| 1993 | 31837 | 11932 |
| 1994 | 32545 | 12188 |
| 1995 | 32882 | 12303 |
| 1996 | 33646 | 12363 |
| 1997 | 34217 | 12349 |
| 1998 | 34742 | 12316 |
| 1999 | 35231 | 12262 |
| 2000 | 35699 | 12194 |
| 2001 | 36116 | 12105 |
| 2002 | 36512 | 12003 |
| 2003 | 36907 | 11899 |
| 2004 | 37293 | 11788 |
| 2005 | 37667 | 11671 |
| 2006 | 38016 | 11543 |
| 2007 | 38388 | 11415 |
| 2008 | 38658 | 11263 |
| 2009 | 38902 | 11104 |
| 2010 | 39111 | 10937 |
| 2011 | 39275 | 10758 |
| 2012 | 39392 | 10566 |
| 2013 | 39460 | 10361 |
| 2014 | 39490 | 10149 |
| 2015 | 39470 | 9928 |

*Note* Gigagrams (Gg) equal $10^9$ grams.

*Source* BTCE estimates.

# APPENDIX III ENVIRONMENTAL DAMAGE COSTS OF TRANSPORT EMISSIONS

Average damage costs have been derived for Australian vehicle emissions (in dollars per kilogram emitted) by reviewing the literature (both Australian and international) on the costs associated with environmental damage by air pollution (table III.1). The unit damage costs in table III.1 are very approximate, and should be treated as likely order of magnitude values. Due to the difficulty in estimating such costs (particularly since the exact effects of air pollution on the human and natural environment are still largely unknown), values across the literature vary by more than a factor of 100.

For Australia, two of the more thorough 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 III.1) are primarily based on data from these two studies. However, costs for emissions of $NO_x$, sulphur oxides ($SO_x$) and CO were not included in the Environment Protection Authority of Victoria (EPAV) or National Road Transport Commission (NRTC) analyses (due to concentrations of these species currently being below recommended acceptable levels for all Australian cities) and approximate costs were estimated using the international literature.

Using the values in table III.1 and average emission rates for Australian road vehicles results in an estimate of 0.11 c/km (with a likely range of 0.02–0.35) as the average damage rate of the Australian motor vehicle fleet. Segal (1995) derived 0.03 c/km (with a likely range of 0.005–0.12) as the health cost of Australian motor vehicle emissions (see note 4 of table III.1). Rates derived overseas (for cities with greater air pollution than is common in Australia cities) are typically much higher—for example, Litman (1994) reviews various US studies, yielding an average of around 4 c/km for damage costs due to air pollution. In the USA, unit costs given for emissions are typically substantially higher than those presented in table 1—for example, the studies reviewed by Litman (1994) derive costs of around \$6/kg for $SO_x$ and \$4/kg for $NO_x$.

TABLE III.1 APPROXIMATE UNIT COSTS OF ENVIRONMENTAL DAMAGE BY AIR-BORNE 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 NOx and NMVOCs, and $0.001 per kg for CO.

4. The primary 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 NOx and NMVOCs are partly based on the assumption that the rate of formation of urban ozone is proportional to the sum of NOx and NMVOC emissions. This is very approximate, since ozone levels depend non-linearly on ambient concentrations of NOx, 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).

# APPENDIX IV FUEL EFFICIENCY TECHNOLOGY FOR CARS—RESULTS TABLES

## IMPLEMENTATION COSTS

The following four tables present marginal and total instrument implementation costs for each of target years 2000, 2005, 2010 and 2015.

TABLE IV.1 CUMULATIVE IMPLEMENTATION COSTS TO 2000

| *Intensity* | *Marginal cost ($/tonne)* | *Total cost ($ million)* |
|---|---|---|
| 20 | -63 | -37 |
| 40 | -22 | -48 |
| 60 | 57 | -25 |
| 80 | 171 | 32 |
| MTS | 196 | 135 |

*Source* BTCE estimates.

TABLE IV.2 CUMULATIVE IMPLEMENTATION COSTS TO 2005

| *Intensity* | *Marginal cost ($/tonne)* | *Total cost ($ million)* |
|---|---|---|
| 20 | -51 | -245 |
| 40 | -14 | -309 |
| 60 | 41 | -145 |
| 80 | 114 | 283 |
| MTS | 162 | 1 035 |

*Source* BTCE estimates.

TABLE IV.3 CUMULATIVE IMPLEMENTATION COSTS TO 2010

| *Intensity* | *Marginal cost ($/tonne)* | *Total cost ($ million)* |
|---|---|---|
| 20 | -40 | -605 |
| 40 | -19 | -872 |
| 60 | 12 | -715 |
| 80 | 50 | -65 |
| MTS | 83 | 1 195 |

*Source* BTCE estimates.

TABLE IV.4 CUMULATIVE IMPLEMENTATION COSTS TO 2015

| Intensity | Marginal cost ($/tonne) | Total cost ($ million) |
|---|---|---|
| 20 | -32 | -991 |
| 40 | -19 | -1 535 |
| 60 | -1 | -1 566 |
| 80 | 22 | -998 |
| MTS | 42 | -315 |

*Source* BTCE estimates.

## TRAVEL, FUEL CONSUMPTION AND EMISSION CHANGES

Tables IV.5 through to IV.7 present the changes in travel, fuel consumption and greenhouse gas emissions for each implementation intensity and target year.

TABLE IV.5 INCREASE IN VEHICLE–KILOMETRES TRAVELLED

*(billion kilometres)*

| Intensity | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|
| 20 | 0.2 | 0.7 | 1.1 | 1.6 |
| 40 | 0.6 | 1.5 | 2.5 | 3.6 |
| 60 | 1.0 | 2.5 | 4.2 | 6.0 |
| 80 | 1.5 | 3.8 | 6.3 | 9.1 |
| MTS | 1.9 | 4.6 | 7.7 | 11.0 |

*Source* BTCE estimates.

TABLE IV.6 DECREASE IN FUEL CONSUMPTION

*(million litres)*

| Intensity | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|
| 20 | 111 | 494 | 990 | 1278 |
| 40 | 211 | 969 | 1887 | 2400 |
| 60 | 299 | 1421 | 2769 | 3523 |
| 80 | 380 | 1892 | 3644 | 4639 |
| MTS | 485 | 2360 | 4611 | 5886 |

*Source* BTCE estimates.

TABLE IV.7 GREENHOUSE GAS EMISSIONS

(million tonnes)

| Year | Base case | 20 | 40 | 60 | 80 | MTS |
|---|---|---|---|---|---|---|
| 1995 | 45.2 | 45.2 | 45.2 | 45.2 | 45.2 | 45.2 |
| 1996 | 46.0 | 46.0 | 46.0 | 46.0 | 46.0 | 45.9 |
| 1997 | 46.6 | 46.5 | 46.5 | 46.5 | 46.5 | 46.4 |
| 1998 | 47.1 | 47.0 | 46.9 | 46.8 | 46.8 | 46.7 |
| 1999 | 47.5 | 47.3 | 47.2 | 47.1 | 47.0 | 46.8 |
| 2000 | 47.9 | 47.6 | 47.4 | 47.2 | 47.0 | 46.7 |
| 2001 | 48.2 | 47.8 | 47.4 | 47.1 | 46.8 | 46.4 |
| 2002 | 48.5 | 47.9 | 47.4 | 46.9 | 46.4 | 45.8 |
| 2003 | 48.8 | 48.0 | 47.2 | 46.6 | 45.9 | 45.1 |
| 2004 | 49.1 | 48.0 | 47.1 | 46.1 | 45.3 | 44.2 |
| 2005 | 49.3 | 48.0 | 46.8 | 45.6 | 44.5 | 43.2 |
| 2006 | 49.6 | 48.0 | 46.5 | 45.0 | 43.6 | 42.0 |
| 2007 | 49.8 | 48.0 | 46.2 | 44.5 | 42.9 | 41.0 |
| 2008 | 49.9 | 47.8 | 45.8 | 43.9 | 42.0 | 39.9 |
| 2009 | 50.0 | 47.6 | 45.5 | 43.3 | 41.3 | 38.9 |
| 2010 | 50.0 | 47.4 | 45.1 | 42.8 | 40.5 | 37.9 |
| 2011 | 50.0 | 47.2 | 44.7 | 42.2 | 39.7 | 37.0 |
| 2012 | 50.0 | 46.9 | 44.3 | 41.6 | 39.0 | 36.1 |
| 2013 | 49.8 | 46.6 | 43.9 | 41.1 | 38.4 | 35.3 |
| 2014 | 49.6 | 46.3 | 43.5 | 40.0 | 37.8 | 34.6 |
| 2015 | 49.4 | 46.0 | 43.1 | 40.1 | 37.2 | 33.9 |

*Source* BTCE estimates.

## SENSITIVITY TESTING

Sensitivity testing was performed on both the discount rate (at 5 and 15 per cent) and the cost of manufacturing the new technology vehicles (33 per cent above and below the original estimate). Tables IV.9 to IV.16 include both marginal and total costs for all target years and intensity levels.

TABLE IV.8 MARGINAL COSTS WITH DISCOUNT RATE OF 5 PER CENT

($/tonne)

| Intensity | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|
| 20 | -74 | -71 | -63 | -59 |
| 40 | -27 | -20 | -31 | -38 |
| 60 | 65 | 57 | 15 | -8 |
| 80 | 197 | 158 | 74 | 30 |
| MTS | 226 | 225 | 126 | 64 |

*Source* BTCE estimates.

TABLE IV.9 MARGINAL COSTS WITH DISCOUNT RATE OF 15 PER CENT

($/tonne)

| Intensity | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|
| 20 | -55 | -38 | -26 | -19 |
| 40 | -18 | -11 | -12 | -11 |
| 60 | 50 | 30 | 9 | 1 |
| 80 | 149 | 84 | 34 | 16 |
| MTS | 172 | 120 | 57 | 28 |

*Source* BTCE estimates.

TABLE IV.10 TOTAL COSTS WITH DISCOUNT RATE OF 5 PER CENT

*($ million)*

| *Intensity* | *2000* | *2005* | *2010* | *2015* |
|---|---|---|---|---|
| 20 | -43 | -336 | -970 | -1 820 |
| 40 | -57 | -424 | -1 417 | -2 881 |
| 60 | -30 | -196 | -1 213 | -3 092 |
| 80 | 36 | 398 | -245 | -2 315 |
| MTS | 154 | 1 439 | 1 662 | -300 |

*Source* BTCE estimates.

TABLE IV.11 TOTAL COSTS WITH DISCOUNT RATE OF 15 PER CENT

*($ million)*

| *Intensity* | *2000* | *2005* | *2010* | *2015* |
|---|---|---|---|---|
| 20 | -32 | -182 | -393 | -575 |
| 40 | -41 | -230 | -558 | -871 |
| 60 | -20 | -109 | -439 | -839 |
| 80 | 29 | 207 | 13 | -425 |
| MTS | 120 | 762 | 874 | 464 |

*Source* BTCE estimates.

TABLE IV.12 MARGINAL COSTS WITH LOW VEHICLE PRICE

*($/tonne)*

| *Intensity* | *2000* | *2005* | *2010* | *2015* |
|---|---|---|---|---|
| 20 | -89 | -63 | -46 | -36 |
| 40 | -70 | -40 | -33 | -28 |
| 60 | -29 | -6 | -14 | -17 |
| 80 | 26 | 39 | 10 | -2 |
| MTS | 77 | 79 | 36 | 14 |

*Source* BTCE estimates.

TABLE IV.13 MARGINAL COSTS WITH HIGH VEHICLE PRICE

*($/tonne)*

| *Intensity* | *2000* | *2005* | *2010* | *2015* |
|---|---|---|---|---|
| 20 | -37 | -40 | -33 | -28 |
| 40 | 27 | 12 | -4 | -11 |
| 60 | 143 | 88 | 37 | 14 |
| 80 | 316 | 189 | 89 | 47 |
| MTS | 315 | 246 | 130 | 69 |

*Source* BTCE estimates.

TABLE IV.14 TOTAL COSTS WITH LOW VEHICLE PRICE

*($ million)*

| *Intensity* | *2000* | *2005* | *2010* | *2015* |
|---|---|---|---|---|
| 20 | -52 | -300 | -702 | -1 111 |
| 40 | -88 | -480 | -1 174 | -1 904 |
| 60 | -100 | -505 | -1 361 | -2 354 |
| 80 | -91 | -358 | -1 225 | -2 412 |
| MTS | -51 | 7 | -677 | -1 966 |

*Source* BTCE estimates.

TABLE IV.15 TOTAL COSTS WITH HIGH VEHICLE PRICE

($ million)

| Intensity | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|
| 20 | -22 | -190 | -508 | -871 |
| 40 | -8 | 139 | -570 | -1 166 |
| 60 | 50 | 214 | -70 | -778 |
| 80 | 156 | 925 | 1 095 | 416 |
| MTS | 321 | 2 063 | 3 067 | 2 596 |

*Source* BTCE estimates.

## DISAGGREGATED COSTS

The final table gives the total costs disaggregated into individual categories, to show both the separate costs and costs incurred by consumers, producers, government and externalities. Only 2015 costs were included but the proportions of costs incurred by each group were similar for all of the target years.

TABLE IV.16 CUMULATIVE DISAGGREGATED COSTS TO 2015

($ million)

| Costs | 20 | 40 | 60 | 80 | MTS |
|---|---|---|---|---|---|
| *Consumers* | | | | | |
| fuel | -2 517 | -4 825 | -7 053 | -9 232 | -11 702 |
| insurance | 103 | 318 | 681 | 1 222 | 1 971 |
| vehicle price | 320 | 985 | 2 104 | 3 775 | 6 090 |
| extra travel | -390 | -864 | -1 424 | -2 098 | -2 487 |
| *Consumer subtotal* | -2 484 | -4 386 | -5 692 | -6 333 | -6 127 |
| *Producers* | | | | | |
| fuel producer profits | 50 | 97 | 141 | 185 | 234 |
| *Producer subtotal* | 50 | 97 | 141 | 185 | 234 |
| *Government* | | | | | |
| fuel excise | 1 329 | 2 547 | 3 723 | 4 874 | 6 177 |
| sales tax | -64 | -197 | -421 | -754 | -1 218 |
| *Government subtotal* | 1 265 | 2 350 | 3 302 | 4 119 | 4 959 |
| *Externalities* | | | | | |
| health | -6 | -13 | -18 | -24 | -30 |
| accidents | 185 | 417 | 701 | 1 055 | 1 279 |
| *Externalities subtotal* | 178 | 404 | 683 | 1 032 | 1 249 |
| **Total** | **-991** | **-1 535** | **-1 566** | **-998** | **315** |

*Note* Any inaccuracies are due to rounding.

*Source* BTCE estimates.

# APPENDIX V VALUATION OF COMMUTER TRAVEL TIME

It was necessary to specify a value of time in order to estimate the costs of the compulsory engine tuning instrument (chapter 6). The valuation of travel time involves complex philosophical and theoretical issues and has generated an extensive literature. Bruzelius (1979) provides a comprehensive survey of the issues.

The value of time to an individual can vary with factors such as income and the purpose of travel. Because the amount of time available to an individual is fixed, an increase in income would generally suggest an increase in the opportunity cost of time. Indeed, most empirical studies have found a positive relationship between income and the value of time, but the precise form of the relationship has not been definitely established.

It is difficult in project evaluations to use values of time that vary for different individuals because of the considerable amount of data that would be required. In the case of transport relating to a single mode such as car travel, variations in the value of time with income may be small enough to be negligible, thereby justifying the use of 'equity' or uniform values.

However, whether or not values of time used in evaluations are adjusted for income effects is a matter of Government policy. Governments generally use uniform values based on equity principles. However, efficiency principles suggest that higher values of time should be used for higher income groups. If such a course of action is followed, there would be a transfer of public resources to higher income groups. The distributional problems that are thereby generated would have to be addressed by means such as compensating payments to affected groups.

Waters (1993, p. 6) observes that the use of equity values of time by governments results in an inconsistent treatment of benefits and costs. This is because cost-benefit studies normally do not make an income adjustment for monetary costs and benefits. But not taking account of the link between income and the value of time means that an implicit income adjustment is made for time savings. Waters notes that the inconsistent treatment of time and non-time costs and benefits could distort project rankings that depend significantly on the relative importance of time compared to monetary benefits and costs.

## VALUES OF TIME

Average wage rates are sometimes used as a proxy for the opportunity cost of commuter travel. This is not necessarily correct because some proportion of travel time may be used in productive work and because some travel (especially long distance travel) is done in employees' own non-work time.

Empirical methods of valuing time are generally of two types: stated preference (interview or survey methods) and revealed preference (observing the actual trade-offs that individuals make between time savings and costs such as tolls paid to travel on shorter or less congested routes). Table V.1 lists some recent estimates of the value of travel time.

TABLE V.1 SELECTED ESTIMATES OF THE VALUE OF TRAVEL TIME

*$ per person-hour (unless otherwise stated)*

| *Source* | *Value of time* |
|---|---|
| BTCE | 15.19 |
| RTA (NSW) | 11.99 (per vehicle) |
| Queensland Transport | 4.82 |
| Transtep | 14.61 |
| Wage rate | 15.40 |

*Sources* ABS (1995b), Nairn (1995), RTA (1990), Queensland Transport (1993) and BTCE estimates based on the results of a survey carried out under contract by the Institute of Transport Studies, Graduate School of Business, The University of Sydney.

Both the Queensland and NSW RTA figures were essentially estimated from revealed preference data. The Transtep estimate was derived from published sources. The wage rate estimate is based on data from ABS (1995).

Behaviour that involves choice can be described using utility equations. Urban commuters, for example, can choose between public transport or driving to work. These two alternatives can be represented in terms of bundles of characteristics such as travelling time, waiting time, fares, vehicle operating costs, convenience, comfort etc.

Where empirical data are available, utility equations that capture consumers' trade-offs between the characteristics can be estimated (Varian 1993, pp. 67-69 provides a non-technical example). Ratios of the marginal utilities of any two attributes provide a measure of the marginal rate of substitution between them. The value of travel time, for example, can be estimated as the ratio of marginal utility of the time spent on a trip to the marginal utility of the cost of the trip (for example, a bus fare).

Under contract to the BTCE, the Institute of Transport Studies (ITS) in the Graduate School of Business, The University of Sydney, estimated utility equations that were used by the BTCE to estimate an average value of travel time for Australian capital cities. Estimation of the utility equations was based on a survey by ITS of 1 257 households in six Australian capital (excluding Darwin and Hobart).

The utility equations estimated by ITS provide two alternative estimates of the value of travel time because they contained two coefficients defined in dollar terms: costing tolls paid during the trip to work, and the cost of fuel used during the trip.

Because tolls are generally paid to gain access to a less congested road (for example toll ways) or to a shorter route such as a bridge, they are arguably the best basis for determining a trade-off between time and cost of travel. Although estimates of the value of travel time based on toll costs are presented in table V.1, they were not used by the BTCE because of some doubt as to their validity. In particular, it was not cleared that household surveyed in cities such as Melbourne had had sufficient experience of tolls to provide an informed response when presented with the choice of faster travel on a tollway and slower travel on other roads.

Fuel cost coefficients could also be used to estimate the value of travel time from utility equations. Their major drawback, however, is that commuters generally fill up with petrol only about once a week. The psychological link (or trade-off) between the cost of fuel and travel time is therefore likely to be relatively weak.

The BTCE chose to base its estimate of the value of travel time on fuel costs, primarily because of the potential uncertainties inherent in survey responses regarding tolls.

Table V.2 lists the value of commuter travel time for each city. An overall national value of $15.19 was obtained by averaging the value of time for each city weighted by its expected population in 1996.

TABLE V.2 VALUE OF COMMUTER TRAVEL TIME BY CITY

*$ per person-hour*

| | *Travel time* | |
|---|---|---|
| *City* | *Value of toll costs* | *Fuel costs* |
| 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.

# GLOSSARY

**Automotive gasoline** (petrol) is a light petroleum oil used as fuel in spark ignition internal combustion engines (other than aviation piston engines). It is treated in refineries to reach a sufficiently high octane number for use in motor vehicles. There are two types of petrol sold in Australia, leaded and unleaded. The leaded form (containing either tetraethyl or tetramethyl lead) is used in motor vehicles manufactured prior to 1986 and the unleaded form is used mainly in post-1985 vehicles.

**Base case projections** are based on the assumption that Australian governments take no action to reduce greenhouse gas emissions (or 'business as usual scenario').

**CAFE**—'corporate average fuel efficiency': the average fuel efficiency of a car producer for all sales within the USA.

**Close coupling** is an automotive engineering practice where the catalytic converter is positioned close to the exhaust manifold, using the heat generated by the engine to speed up the catalyst attaining its operating temperature.

**Clunkers** are cars older than 12 years and are assumed to have higher rates of non-$CO_2$ emissions and higher fuel usage than the average vehicle of equal age.

**$CO_2$ equivalent** implies the mass of $CO_2$ necessary to have the same radiative (or warming) effect as the mass of greenhouse gas emitted (see appendix I).

**Cycle tests** are carried out on a chassis dynamometer, simulating different driving conditions to measure fuel consumption and emissions.

**Downsizing** means replacing one car with a smaller model, either as a producer or a consumer.

**Emission factors** are 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.

**Emissions intensity** refers to the amount of non-$CO_2$ greenhouse gases produced per litre of fuel burned.

**End use** refers to emissions resulting solely from vehicle operation (see also full fuel cycle).

**Fluorocarbons** (FCs) comprise various gases used as refrigerants in vehicle air-conditioners. These include chlorofluorocarbons (CFCs), hydro-fluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs). The main refrigerant in Australian vehicle air-conditioners is a chlorofluorocarbon denoted by CFC-12. However, Australian legislation, under the provisions of the Montreal Protocol on Ozone Depleting Substances, calls for the phasing out of chlorofluorocarbon use. All vehicle air-conditioning systems manufactured after the end of 1994 use CFC substitutes. For new systems, the main CFC replacement is a hydrofluorocarbon denoted by HFC-134a.

**Fuel efficiency** is the number of kilometres travelled by a vehicle per litre of fuel.

**Fuel intensity** is the inverse of fuel efficiency, and refers to the intensity of fuel use for road vehicles. It is typically measured in litres per 100 kilometres.

**Fugitive emissions** 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 gasoline vehicles and the release of fluorocarbons from vehicle air-conditioners.

**Full fuel cycle** refers to emissions resulting from end-use plus those resulting from feedstock extraction and refining, power generation, and energy distribution.

**Global warming potential (GWP)** is an index defined as the warming effect over a given period due to an emission of a particular gas, relative to an equal mass of $CO_2$ (see appendix I).

**Greenhouse effect** is 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.

**Greenhouse gas emissions** analysed in this working paper are carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), oxides of nitrogen other than nitrous oxide ($NO_x$), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs).

**Gross calorific value** (GCV) is 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 (HHV).

**Liquefied petroleum gas** (LPG) is a light petroleum liquid produced by compressing petroleum vapour, used in specially modified internal combustion engines. In Australia, LPG sold for automotive purposes is primarily a mixture of 70 per cent propane and 30 per cent butane, with the precise composition varying with application, season and region.

**Logistic curve** refers to a graph of

$$g(t) = k/(1+ae^{-bt}),$$

for time $t$, with $k$, $a$, $b$ constants. It increases with $t$ and has an upper asymptote of $k$. The logistic curve is typically used to model market penetration of a new product. The curve grows slowly at first, but then takes of with a period of rapid growth, followed by a levelling off as the product reaches market saturation.

**Natural gas** (NG) consists primarily of methane (around 90 per cent, with traces of other gaseous hydrocarbons, nitrogen and carbon dioxide) and occurs naturally in underground deposits. As a transport fuel, it is generally used in compressed or liquefied form.

**Rebound effect** refers to an increase in the amount of travel resulting from a fall in fuel prices or other costs.

**'Snapshot' years** are those for which results are given on the progress of implementation of an instrument. For any year in the period 1996–2015, a reduction in greenhouse gas emissions or the cost of achieving the reduction refers to the cumulative total from 1996 up to, and including, the reference year. However, to facilitate presentation of the information generated during the analysis, this working paper generally presents results only for the 'snapshot' years 2000, 2005, 2010 and 2015.

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| ABS | Australian Bureau of Statistics |
| AEC | Australian Environment Council |
| ADIPG | Australian Draft Inventory Preparation Group |
| AGPS | Australian Government Publishing Service |
| BTCE | Bureau of Transport and Communications Economics |
| CADDET | Centre for the Analysis and Dissemination of Demonstrated Energy Technologies |
| CBCS | Commonwealth Bureau of Census and Statistics |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| DASET | Department of the Arts, Sport, the Environment and Territories |
| DEST | Department of the Environment, Sport and Territories |
| DME | Department of Minerals and Energy of NSW |
| DPIE | Department of Primary Industry and Energy |
| ECMT | European Conference of Ministers of Transport |
| EPA NSW | Environment Protection Agency of NSW |
| EPAV | Environment Protection Agency of Victoria |
| FORS | Federal Office of Road Safety |
| HMSO | Her Majesty's Stationery Office |
| IEA | International Energy Association |
| IPCC | Intergovernmental Panel on Climate Change |
| ITS | Institute of Transport Studies |
| NELA | Nelson, English, Loxton and Andrews, Pty Ltd |
| NGGIC | National Greenhouse Gas Inventory Committee |
| NRTC | National Road Transport Commission |
| OECD | Organisation for Economic Cooperation and Development |
| PSA | Prices Surveillance Authority |
| SPCC | State Pollution Control Commission |
| STSG | State Transport Study Group |
| RCEP | Royal Commission on Environmental Pollution |
| RCNPT | Royal Commission on National Passenger Transportation |
| USEPA | United States Environmental Protection Agency |

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## ABBREVIATIONS

| | |
|---|---|
| ABS | Australian Bureau of Statistics |
| ADIPG | Australian Draft Inventory Preparation Group |
| ADR | Australian Design Rules |
| BTCE | Bureau of Transport and Communications Economics |
| CAFE | corporate average fuel efficiency |
| cc | cubic centimetres |
| $CH_4$ | methane |
| CO | carbon monoxide |
| $CO_2$ | carbon dioxide |
| ECU | European currency unit |
| EPA NSW | Environmental Protection Agency of New South Wales |
| EPAV | Environment Protection Authority of Victoria |
| FORS | Federal Office of Road Safety |
| g | gram |
| GDP | gross domestic product |
| Gg | gigagram |
| GWP | global warming potential |
| HC | hydrocarbon |
| IEA | International Energy Association |
| IPCC | Intergovernmental Panel on Climate Change |
| km | kilometre |
| LCV | light commercial vehicle |
| LPG | liquefied petroleum gas |
| Mj | megajoule |
| MVC | Motor Vehicle Census |
| MVPER | motor vehicles per thousand persons |
| $N_2O$ | nitrous oxide |
| NAFC | national average fuel consumption |
| NELA | Nelson, English, Loxton and Andrews, Pty Ltd |
| NG | natural gas |
| NMVOC | non-methane volatile organic compound |
| $NO_x$ | oxides of nitrogen |
| NRMA | National Roads and Motorists Association |
| NRTC | National Road Transport Commission |
| OBD | on-board diagnostics |
| OECD | Organisation for Economic Cooperation and Development |
| OTA | Office of Technology Assessment (USA) |

| | |
|---|---|
| PSA | Prices Surveillance Authority |
| SMVU | Survey of Motor Vehicle Use |
| $SO_x$ | sulphur oxides |
| VKT | vehicle kilometres travelled |