Costs of Reducing Greenhouse Gases in Australian Transport

Working Paper

The Bureau of Transport and Communications Economics has provided a comprehensive analysis of the range of possible measures for reducing greenhouse gases in the transport sector. The objective of the papers from the BTCE's greenhouse gas project is to: provide information on the work being undertaken by the BTCE; and expose the BTCE's analysis to comment by others.

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Bureau of Transport and Communications Economics

WORKING PAPER 10

COSTS OF REDUCING GREENHOUSE GASES IN AUSTRALIAN TRANSPORT

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FOREWORD

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

The objective of the papers from the BTCE's greenhouse gas project is to:

- provide information on the work being undertaken by the BTCE; and

- expose the BTCE's analysis to comment by others.

Final reports on various aspects of the BTCE's work will take into account comments received.

'Costs of Reducing Greenhouse Gases in Australian Transport' outlines the BTCE's proposed overall methodology in carrying out its project. Subsequent Working Papers will focus on more specific aspects, particularly costing of the policy instruments set out in appendix I.

Contributers to this Working Paper 10 were Dr Leo Dobes, Ms Patricia Green, Ms Lucy Firth, Ms Soy Nia Salerian, Mr David Cosgrove and Ms Anita Scott-Murphy.

Leo Dobes
Research Manager

Bureau of Transport and Communications Economics
Canberra
November 1993

BTCE

Transport Externalities Branch

Postal address: GPO Box 501
Canberra ACT 2601
Fax: (06) 274-7170

Research Manager:
Dr Leo Dobes Ph: (06) 274 6806
Internet: leod%environ%btce@smtpgate.dotc.gov.au

Executive Assistant:
Ms Karen Subasic Ph: (06) 274 6074

GREENHOUSE GASES
Team Leader: Ms Patricia Green Ph: 274 6863

Ms Soy Nia Salerian Ph: 274 6715
Ms Lucy Firth Ph: 274 6707
Mr David Cosgrove Ph: 274 6726
Ms Anita Scott-Murphy Ph: 274 6859

URBAN EXTERNALITIES
Team Leader: Dr Franzi Poldy Ph: 274 6140

Mr Kay Loong Ph: 274 6740
Ms Trisha Dermody Ph: 274 6862

TRANSPORT SAFETY (from December 1993)
Team Leader: Mr Joe Motha Ph: 274 6828

Mr Bogey Musidlak Ph: 274 6833
Ms Seu Cheng Ph: 274 6787
Ms Catharina Williams Ph: 274 6099

TRANSPORT & COMMUNICATIONS INDICATORS
Team Leader: Dr David Gargett Ph: 274 6879

Ms Vijole Donda Ph: 274 6098
Mr Gunter Haselberger Ph: 274 6841
Ms Anne Paal Ph: 274 6724

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ABSTRACT

Australian governments agreed in October 1990 to stabilise greenhouse gas emissions at 1988 levels by the year 2000, and to reduce them by a further 20 per cent by the year 2005. The BTCE was commissioned to estimate the costs of instruments to implement this objective in the transport sector. The BTCE's objective is to identify a least-cost combination of measures and to analyse their equity effects. The analytical framework relies essentially on estimating the economic costs of each instrument at various levels of abatement. Economically efficient combinations of instruments will in principle involve equality of marginal costs. Evaluation of costs will include changes in consumer surplus and benefits from reductions in other transport externalities (noxious emissions, congestion, noise and accidents). Numerical optimisation techniques will be used to take into account interactions between different instruments.

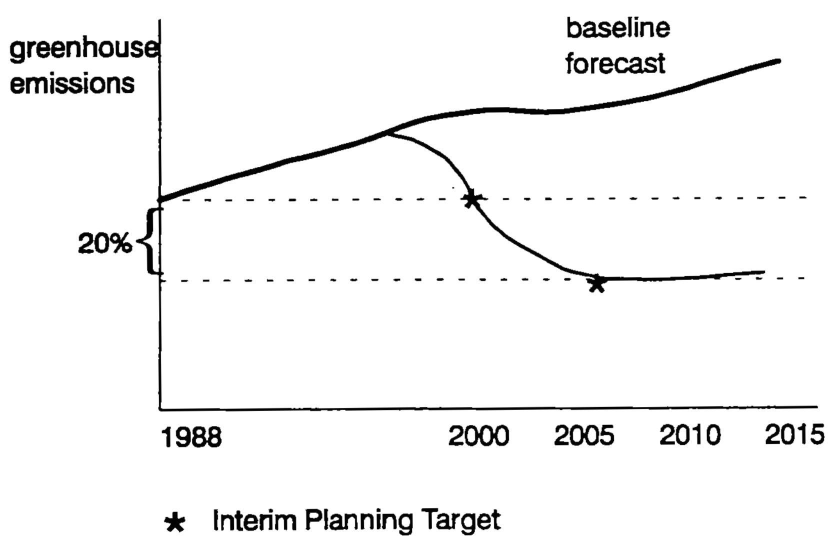
A. BACKGROUND

(i) Government policy

In October 1990 Australia adopted an Interim Planning Target (IPT) to stabilise greenhouse gas emissions (not controlled by the Montreal Protocol on Substances that Deplete the Ozone Layer), based on 1988 levels by the year 2000, and to reduce these emissions by 20 per cent by the year 2005. The IPT has a caveat that Australia will not implement response measures that would have net adverse economic impacts nationally or on Australia's trade competitiveness, in the absence of similar action by major greenhouse gas producing countries.

The Government's IPT is illustrated in figure 1. The base case assumes that no additional measures are implemented specifically by the Government to reduce greenhouse gases; it will contain assumptions about output and population growth, real fuel price developments and fuel efficiency improvements. Technological developments or energy-saving measures that are likely to be introduced for normal commercial reasons, or as part of ongoing government policies and programs, will be included in the calculation of the base case; that is, a 'business-as-usual' scenario.

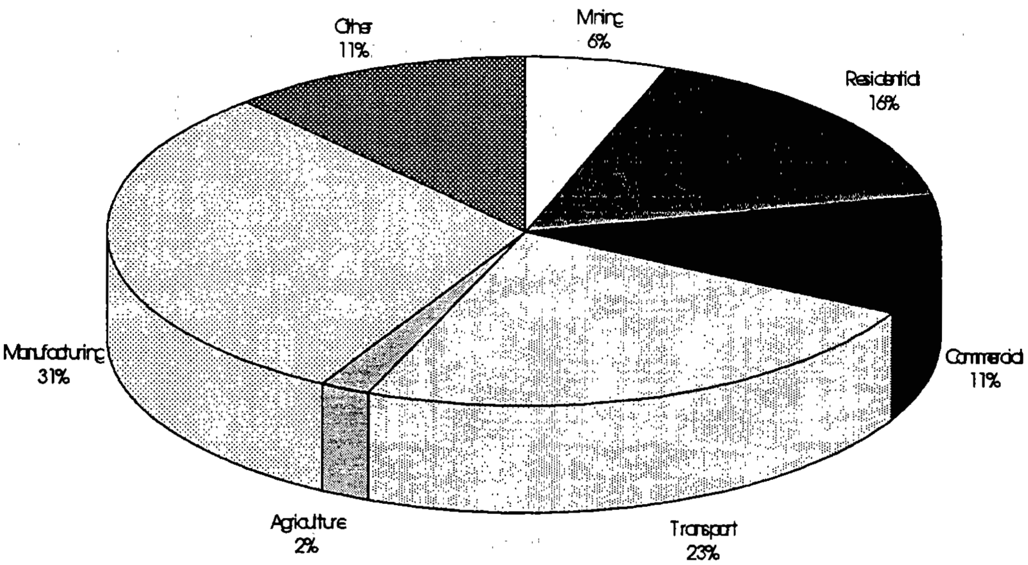
Figure 1 Interim Planning Target



Australian governments endorsed the National Greenhouse Response Strategy (NGRS) at the Council of Australian Governments meeting on 7 December 1992. The IPT was used as a basis for development of the strategy, which contains mainly 'no regrets' measures.

The NGRS foreshadowed that the Commonwealth would commission a study by the Bureau of Transport and Communications Economics (BTCE) of the potential responses, costs and external benefits in the transport sector relating to measures targeted at energy conservation. In this context, the Prime Minister announced in his 21 December 1992 Statement on the Environment that the BTCE would provide a comprehensive analysis of the range of possible measures for reducing greenhouse gas emissions in the transport sector. This was, in part, in recognition of the large proportion of total carbon-dioxide emissions attributable to transport, as depicted in figure 2 below.

Figure 2 Australian Carbon Dioxide Emissions by Sector 1990-91



Source: ABARE (1993a).

(ii) Australian Transport Activity

In 1991, the Australian transport fleet consisted of about 10.1 million vehicles, of which 8 million were passenger vehicles (ABS, 1993). In 1990-91, the domestic passenger transport task amounted to about 252 billion passenger kilometres, and around 287 billion tonne kilometres for freight[1].

Australian domestic passenger transport is dominated by cars. About 76 per cent of all passenger kilometres are accounted for by cars, with bus, rail and air travel moving approximately 7.3, 4.1 and 6.2 per cent of total passenger kilometres respectively.

1 Domestic transport is defined in this paper to exclude off-road mobile equipment used in agriculture and mining, and off-shore uses such as fishing and pleasure boating.

Domestic freight, in terms of aggregate tonne-kilometres, is split fairly evenly between road (30.7 per cent), rail (30.6 per cent) and sea (32.6 per cent). Air transport accounts for 0.05 per cent of total tonne-kilometres and pipelines around 6 per cent. The share of road transport has been increasing steadily over time (in 1976 road carried less than 18 per cent of total tonne-kilometres).

According to BTCE estimates, in 1990-91 the transport sector emitted about 68 million tonnes of carbon dioxide, the main greenhouse gas after water vapour (table 2). Of the four transport modes, road transport is the largest emitter of carbon dioxide, contributing about 77 per cent of the total (figure 3). Passenger cars and freight vehicles emitted about 64 per cent and 33 per cent respectively of the road transport contribution (figure 4). Rail transport's share was about 5 per cent for the same year. A summary of energy use by mode is presented in table 1.

Table 1 **Estimated Direct Energy Consumption by Australian Transport, 1990-1991, (PJ)**

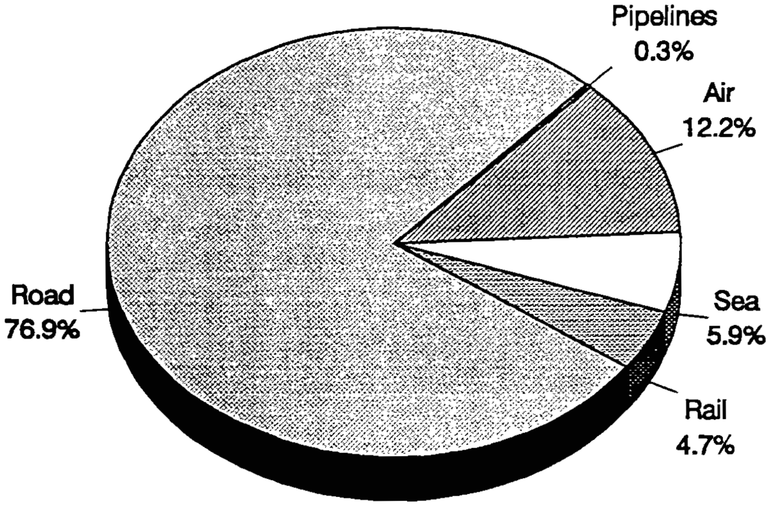
Transport Mode	Passenger		Freight		Total
	Urban	Non-Urban	Urban	Non-Urban	
DOMESTIC TRANSPORT					
Road					
Passenger Vehicles	382.27	158.61	..	..	540.88
Motorcycles	2.06	1.40	..	..	3.46
Light Commercial Vehicles	n.a.	n.a.	n.a.	n.a.	115.24
Trucks	n.a.	n.a.	n.a.	n.a.	152.17
Buses	9.94	7.31	..	..	17.25
Sub-total Road					829.00
Rail					
Trams	0.79	..	..	..	0.79
Government Trains	10.00	2.78	..	23.82	36.60
Non-Government Trains	..	..	..	4.54	4.54
Sub-total Rail	10.79	2.78	..	28.36	41.93
Air					
Domestic Airlines	..	n.a.	..	n.a.	57.25
General Aviation[a]	..	n.a.	..	n.a.	3.78
Sub-total Air	..	n.a.	..	n.a.	61.03
Sea, Coastal	..	n.a.	..	n.a.	24.66
Pipelines[b]	..	..	..	3.52	3.52
Total Domestic	n.a.	n.a.	n.a.	n.a.	960.16
INTERNATIONAL TRANSPORT					
Air					
uplifted in Australia[c]	..	n.a	..	n.a.	70.90
uplifted outside Australia[d]	..	n.a	..	n.a.	94.75
Sea					
uplifted in Australia[c]	..	n.a	..	n.a.	27.92
uplifted outside Australia[d]	..	n.a	..	n.a.	205.70
Total International	..	n.a	..	n.a.	399.27

a. All non scheduled flying activities other than flying activities performed by major airlines.
b. High volume, long distance transmission of crude oil, condensate, LPG, ethane, natural gas and product (refined oil) only.
c. Fuel purchased in Australia by international transport carriers.
d. Estimated proportion of total international bunker fuel due to the carriage of Australian imports and exports.

n.a. data not available
.. nil or not applicable

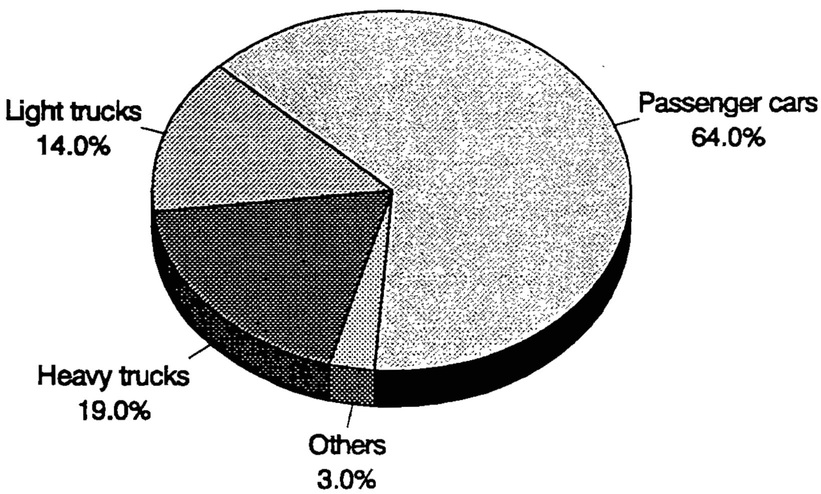
Source: Apelbaum Consulting Group Pty Ltd (1993).

Figure 3 **Carbon Dioxide Emissions from the Transport Sector, 1990-91**



Source: BTCE (1993a).

Figure 4 **Carbon Dioxide Emissions from the Road Transport Sector, 1990-91**



Source: BTCE (1993a).

Table 2 Emission Estimates for Australian Transport, 1990-91

	Emission Type (kilotonnes)					
MODE	Carbon dioxide	Methane	Nitrous oxide	Nitrogen oxides	Carbon monoxide	NMVOCs
Road	52354	20.91	3.95	386.13	3388.92	484.90
Cars	33581	16.85	3.49	194.14	2682.45	366.93
Rail	3207	0.15	0.05	41.90	14.21	3.04
Air	8268	0.43	0.12	32.89	93.54	3.83
Domestic	3825	0.30	0.06	14.84	86.07	2.71
International	4443	0.12	0.07	18.05	7.47	1.12
Sea	3995	0.35	0.10	89.46	46.24	9.45
Domestic	2124	0.26	0.05	40.14	43.20	7.62
International	1870	0.08	0.05	49.32	3.04	1.83
Pipeline	226	0.00	0.01	0.24	0.06	0.00
Total	68049	21.83	4.22	550.62	3542.98	501.22
Domestic	61736	21.62	4.11	483.25	3532.47	498.27
International	6313	0.21	0.12	67.37	10.51	2.95
Transport contribution to Australian emissions (per cent)	23	1	2	39	26[a]	49
Contribution to transport greenhouse emission(per cent of CO_2 equivalent)[b]	83.3	0.6	1.4	5.4	4.3	4.9

a. Transport activity contributes around 90 per cent of energy-related carbon monoxide emissions. The bulk of Australian CO emissions is due to savannah burning.
b. IPCC (1992) estimates of GWPs.

Notes:

1. NMVOCs = Non-methane volatile organic compounds.
2. The carbon dioxide figure assumes full combustion of fuel carbon content.
3. The greenhouse contribution estimates are very approximate. The values for NO_x and NMVOCs would be upper bounds and the value for carbon monoxide would be lower bound.
4. International transport emissions relate to those due to burning transport fuel purchased in Australia.

Source: BTCE (1993a).

(iii) Characteristics of Greenhouse Gases

Some of the solar radiation received by the earth is reflected back into space by the planetary surface and atmosphere, including clouds. The remainder is mostly absorbed by the earth's surface, thereby warming it. The infra-red radiation emitted upwards from the heated ground is strongly absorbed by certain atmospheric constituents, the so-called 'greenhouse gases'. The greenhouse gases re-emit the infra-red radiation both upwards and downwards, serving to maintain the global surface temperature at over 30 degrees warmer than it would otherwise be.

The major greenhouse gases are water vapour, carbon dioxide, methane, nitrous oxide, chlorofluorocarbons (CFCs) and ozone. All occur naturally, except CFCs which are man-made. However, concentrations of some greenhouse gases are increasing substantially as a result of human activity, creating the so-called 'enhanced' or 'anthropogenic' greenhouse effect. International concern has therefore focussed on the likely additional warming effects on the earth due to human activity.

Australia accounts for around 1.1 per cent of global net[2] greenhouse gas emissions, ranking ninetieth among countries contributing to the greenhouse effect; and eleventh in per capita terms (WRI, 1990).

The transport sector generates both 'indirect' and 'direct' greenhouse gases. Carbon dioxide, methane, water vapour, nitrous oxide and CFCs are the main direct greenhouse gases emitted from the transport sector. Indirect greenhouse gases such as carbon monoxide, oxides of nitrogen and non-methane hydrocarbons do not have a strong radiative effect themselves, but influence atmospheric concentrations of the direct greenhouse gases. For example, carbon monoxide largely oxidises to carbon dioxide within a year, and it reacts so as to reduce methane and ozone removal from the atmosphere.

Ozone is a potent direct greenhouse gas, but is not emitted by transport vehicles. It is formed by photochemical reactions involving atmospheric oxygen and a variety of vehicle emissions. These gases, the most important of which are NO_x and volatile organic compounds (VOCs), are known as ozone precursors. Some direct greenhouse gases (such as methane) have both direct effects and indirect effects (such as decomposition to produce carbon dioxide or aiding the formation of ozone).

Methane and nitrous oxide make only relatively minor contributions to total transport emissions. Chlorofluorocarbons are to be phased out by 1997 under the Montreal Convention.

Though carbon dioxide is the major greenhouse gas emitted, the contributions of other gases are important, even in the transport sector. The warming effect of a greenhouse gas

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2 Net of greenhouse gas sinks. That is, gases released into the atmosphere less those absorbed.

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 Carbon Dioxide equivalents. This is done on the basis of the *greenhouse warming potential* (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 carbon dioxide.

Representative GWP values calculated for the main greenhouse gases by the Intergovernmental Panel on Climate Change (IPCC) are given in table 3. 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) has estimated global warming potential factors for three time periods; 20 years, 100 years and 500 years. Most analyses in this area (including IEA 1992) utilise the 100 year values presented in table 3. The BTCE has traditionally calculated emissions on this basis.

Since ozone is a derived greenhouse gas, it is not normally assigned a GWP. Its contribution is attributed to the indirect effects of ozone precursors (such as CO, VOCs and NO_x). Due to the complexity of such derived effects, the GWPs presently derived for indirect greenhouse consequences are indicative only. There is considerable uncertainty in these values, and their refinement is a topic of current research at the international level. In fact, the IPCC (1992) has stated that 'care must be exercised in applying GWPs in the policy arena'. Concerning the exactness of the indirect values in table 3, the IPCC (1992) state the only certainties are that:

- the GWP for methane is a positive number, and
- CO, VOCs and NO_x 'will affect the radiative balance of the atmosphere through changes in tropospheric ozone'.

Table 3 **Characteristics of the Major Greenhouse Gases, including Greenhouse Warming Potentials (GWP)**

Trace Gas	Average Atmospheric concentration (ppm)	Average Atmospheric Residence (years)	GWP (100 years)	Aust. Anthropogenic Emissions (Mt)	Contribution to national greenhouse forcing (per cent)
Direct					
CO_2	353.0	120	1	270.0	48
CH_4	1.7	11	26	4.7	22
N_2O	0.3	132	270	0.2	10
CFCs	< 0.001	50-120	3000-7000	0.01	10
Indirect					
CO	0.1-40	0.4	3	13.2	7
NO_x	0.01-0.2	< 1	8	1.1	2
NMVOCs	0.2-0.5	< 1	11	0.9	2

Notes:

1. ppm = parts per million by volume
2. The Greenhouse Warming Potentials (GWP) are global averages, for temperature increases over a 100 year period, relative to carbon dioxide.
3. Methane has both direct and indirect effects, which have been summed to derive the figures in the table.
4. NMVOCs refers to Non-methane volatile organic compounds (ie. VOCs less methane, a direct greenhouse gas).

Sources: BTCE (1993a); Intergovernmental Panel on Climate Change (1992).

B. CONCEPTUAL APPROACH

(i) Optimal Level of Abatement

Standard economic analysis of environmental problems is usually in terms of a diagram such as figure 5.

As the amount of existing pollution is reduced, the additional (marginal) cost of further reduction increases. This is represented by an upward-sloping Marginal Abatement Cost (MAC) curve. The MAC can be thought of as a supply curve of pollution reduction; that is the cost of taking measures to reduce greenhouse gas emissions. (It does not represent the cost of any damage caused by the greenhouse effect itself).

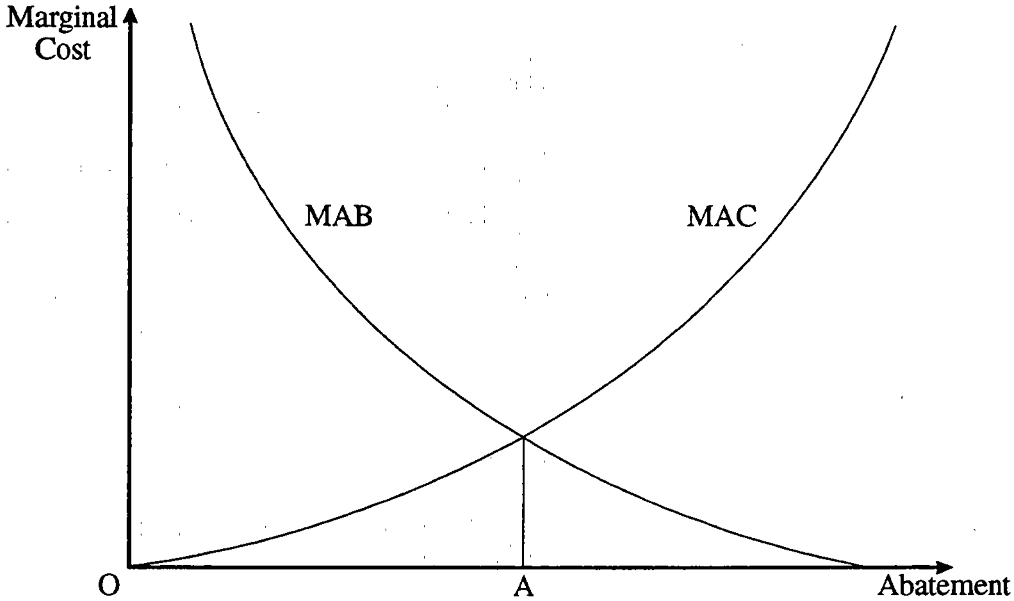
As the amount of abatement increases, additional abatement generates decreasing levels of utility or benefit, giving a downward sloping demand function termed the Marginal Abatement Benefit (MAB) curve.

The optimal amount of pollution abatement is determined by the equality of MAC and MAB. In figure 5 the optimal (most efficient) level of abatement is A.

In the case of greenhouse gas reduction it would be very difficult, if not impossible, to determine a MAB curve. Research is being conducted by agencies such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and at an international level by the Intergovernmental Panel on Climate Change (IPCC), on the benefits of reducing greenhouse gases in terms of avoiding global warming.

Although atmospheric concentrations of carbon dioxide are known to be increasing, considerable uncertainty remains about the likely effect. A 'missing' carbon sink does not permit accurate estimation of a greenhouse gas inventory; increased warming may result in higher uptake rates of carbon by biomass; and warming may increase water vapour and hence the cloud cover (Pearman, 1990). Even the radiative effect of a number of greenhouse gases is not accurately known.

Figure 5 Optimal Level of Abatement



Apart from these macroscopic uncertainties, regional models can provide only approximate indications of the effects of warming for different areas of Australia. Because the negative consequences of the enhanced greenhouse effect are uncertain, its costs cannot be estimated; and hence it is also not possible to estimate the benefits of any abatement measures.

Since no MAB curve is able to be derived, an optimal level of reduction of greenhouse emissions (A) cannot be determined. The objective of the study is thus limited to determining the minimum cost combination of instruments to reduce emissions; that is, to identify the MAC curve in figure 5 for Australian transport.

Although an optimal target reduction in greenhouse emissions cannot be determined, the MAC curve can be used by policy-makers to estimate the cost of achieving different reduction levels, including any share of the interim planning target that might be apportioned to transport[3].

(ii) 'Insurance' against Global Warming

In the face of the uncertainties mentioned in the last section, it is tempting to call for further research and to postpone action in the meantime. Critics, however, claim that this is equivalent to making the unwarranted assumption that the costs of global warming are small or the risk remote. If the consequences of doing nothing are potentially catastrophic, it is held, we should err on the side of caution. This is the so-called 'precautionary principle', according to which uncertainty and lack of data should not be used to justify inaction.

The 'precautionary principle' provides a warning against complacency and inaction, but it does not tell us what to do, what measures to adopt, or identify the desirable level of emissions reduction.

Manne and Richels (1991) have considered one formulation of this problem of 'decision making under uncertainty'. They consider possible hedging strategies and how they depend on the potential damage due to greenhouse induced climate change, and the timing and accuracy of climatological research. Their work focuses on the extent to which costly emission reduction measures should be introduced *before* the climatological uncertainties are resolved.

While it may be doubted whether the Manne and Richels formulation captures the full complexity of the policy dilemma, or could be used in practice, it does highlight the fact that even 'decision making under uncertainty' requires information. It assumes, for example, that the costs of the emission reduction measures are known. Determining these costs for the transport sector is the aim of the BTCE study.

When these costs become available it will be possible to formulate appropriate hedging strategies pending resolution of the more fundamental climatological uncertainties. The focus will be on reducing the impact of greenhouse gas emissions in the least costly way. To the extent that costless 'no regrets' measures[4] are available, they will be the preferred options.

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3 It needs to be noted that any such target will (except by chance) be 'arbitrary' in the sense that it will not be determined on the basis of optimal economic efficiency.

4 A good example of a 'no-regrets' action by a private entity is reported by Australian Institute of Petroleum Ltd (1991). While investigating the costs of reducing carbon dioxide emissions from their plants 'the refineries were able to identify a number of profitable opportunities' (p.6). That is, small levels of carbon dioxide reductions were achieved with savings or no cost.

(iii) International Dimension of Greenhouse Emissions

A commodity is called a 'public good' if its consumption by any one person does not reduce the amount available (or degrade the quality) to others. This quality is referred to as 'non rivalrous' consumption. An alternative perspective is that the provision of a 'public good' to any one individual means that it is available at no additional cost to all other individuals. Pure public goods are also said to be 'non-excludable' because there is no technical or market-based means of excluding any specific individual from consuming them. Defence, 'free to air' broadcasting and lighthouses are often given as examples of pure public goods, although they may not be so under conditions of congestion (consumption by many individuals).

Some externalities also possess elements of 'publicness' or concurrence in consumption. For example, an aesthetic building may provide a benefit to passers-by, and no one person's enjoyment will reduce others' enjoyment. Negative externalities such as air pollution can also be public in nature because any one person's exposure to, say, unpleasant odours or reduced visibility, will not increase or decrease the amount that others are exposed to or consume.

Assuming that they have negative economic or social consequences, greenhouse gas emissions can be considered to be public 'bads'. No individual's exposure to (or consumption of) climatic change or greenhouse emissions affects another's. This is true both on a local level (eg Australia) and on an international basis.

As a corollary, a reduction in greenhouse emissions can be considered to be a public 'good' because the benefit is available to all. Individuals can neither be excluded nor exclude themselves from the benefit. Once a reduction has been achieved, there is no additional cost involved in making the benefit available to all.

If an individual or individual countries reduce, at their own expense, the amount of greenhouse gases that they emit, others will gain an equal amount of benefit. There is therefore no incentive by others to incur the costs of reducing emissions. By waiting for others to reduce emissions, they are able to 'free-ride' and gain the benefits without cost to themselves.

Because others cannot be excluded from the benefits generated, no individual or country can charge others to recoup costs. It will thus not be worthwhile for any individual or country to implement reduction measures unless such measures generate other benefits. From this point of view, the qualifications in the Australian Government's Interim Planning Target (implementation should not have net adverse economic impacts in the absence of similar action by other countries) is fully justifiable.

In the extreme case, even if Australia alone eliminated all of its greenhouse emissions, the costs to the nation would be very large. However it is likely that there would be little if any consequential reduction in projected levels of global climate change. This can be represented in figure 5 as the virtual absence of a marginal benefit curve.

C. METHODOLOGY

(i) Partial versus General Equilibrium Approach

The costs of greenhouse gas reduction measures could be examined on the basis of either of two approaches. Either a general equilibrium model could be used, or individual measures could be costed on a partial equilibrium basis in isolation from the rest of the economy.

A partial equilibrium approach lends itself better to a more detailed examination of relevant factors and variables. Conceptually, however, a partial equilibrium approach only provides a first approximation.

Abatement measures that affect transport activities may impose costs beyond the transport sector. This could result in a decrease in production and in turn impose broader economic costs. If interactions with the rest of the economy are not large, for example where an instrument encourages a modal shift from cars to say a new light rail system, and the shift does not have an impact on other sectors, then this does not pose a problem. On the other hand, if an instrument aimed at encouraging the use of natural gas in vehicles was introduced, its impact could extend beyond transport to other energy use sectors. The increased demand for natural gas in transport, for instance, could raise its price if there is a limited domestic supply. Households may respond by converting their appliances from natural gas back to cheaper but more greenhouse gas emitting fuels such as electricity.

The enhanced greenhouse effect is a global problem. Any measures implemented to affect Australian transport should therefore be analysed not only with regard to feedback effects in other sectors of the Australian economy, but also in a wider international context. International oil prices (and hence fuel prices), for example, would be affected by reduced demand if a carbon tax was imposed in a number of countries simultaneously, rather than in Australia alone.

The global nature of the greenhouse phenomenon requires a model that incorporates international activity. If other countries are simultaneously implementing greenhouse reduction measures, a general equilibrium model should take into account any global feedback mechanisms, such as effects on international commodity prices.

There are still relatively few global models that focus on the costs of greenhouse reduction. The OECD Secretariat has developed the GREEN Model, with the explicit aim of quantifying the economy-wide and global costs of policies to curb carbon dioxide emissions. Other global models include Edmonds and

Reilly, Manne and Richels, Walley and Wigle and the IEA model (OECD, 1992). However, none of these is able to deal adequately with the detail required to estimate the costs of measures implemented in countries such as Australia.

While the BTCE is not equipped to carry out a general equilibrium analysis in the global context, the final stages of analysis may involve incorporation of the likely effect of concerted abatement measures on a global scale. It is not clear yet whether this can most easily be done by estimating shadow prices for a number of key variables, or by adjusting parameters in a general equilibrium model developed specifically for the international economy.

(ii) Marginal Cost Analysis

Emissions reduction will be achieved most efficiently where the marginal costs of implementing various measures are equal. If two instruments for reducing greenhouse gas emissions are considered, the cost of achieving any given level of reduction will be minimised when the level of reduction attributed to each instrument is set so that the marginal costs are equal.

The condition of equal marginal costs can be stated formally as in equation (1):

(1)
$$\frac{\Delta C}{\Delta x_1}=\frac{\Delta C}{\Delta x_2}=\ldots\frac{\Delta C}{\Delta x_i}=\ldots=\frac{\Delta C}{\Delta x_n}$$

where: C is the cost of reducing greenhouse gases,
x_i is the level of the i^{th} instrument in a series of n instruments

This is known as the first order cost minimising condition.

One measure could be a regulatory instrument such as parking restrictions in one or several capital city CBDs. Table 4 assumes that as parking restrictions are introduced, reductions in carbon dioxide emissions might occur quickly. After a certain point, however, additional reductions might be almost unachievable at any cost; for example after all city streets have been blocked off to vehicles and essential services start to be affected.

Table 4: **Hypothetical Cost of Reducing Emissions by Parking Restrictions in CBD Areas**

Reduction in CO_2 (tonnes)	Total Cost	Marginal cost
1	10	
		3
2	13	
		4
3	17	
		13
4	30	
		20
5	50	

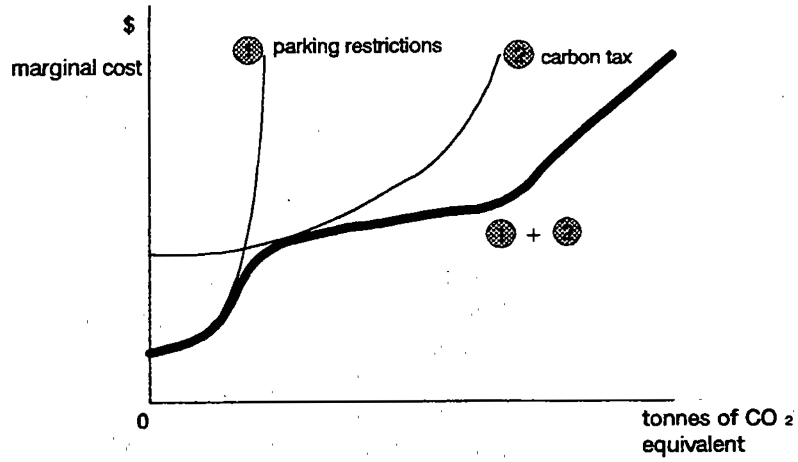
A second measure may be the introduction of a carbon tax. In table 5 the marginal cost of reducing greenhouse gas emissions increases at a steady rate initially because it is assumed that the tax is phased in to allow for easy adjustment. As further emission reductions are made, the costs are likely to increase more rapidly because increasingly higher tax rates are required.

Table 5: **Hypothetical Cost of Reducing Emissions by Introducing a Carbon Tax.**

Reduction in CO_2(tonnes)	Total Cost	Marginal Cost
1	20	
		2
2	22	
		4
3	26	
		7
4	33	
		12
5	45	

Marginal cost functions can be summed horizontally to produce an overall marginal cost function. Such a summation is shown in figure 6, where the sum of curves 1 and 2 represents the composite marginal cost curve.

Figure 6: Composite Marginal Cost Curve for Transport



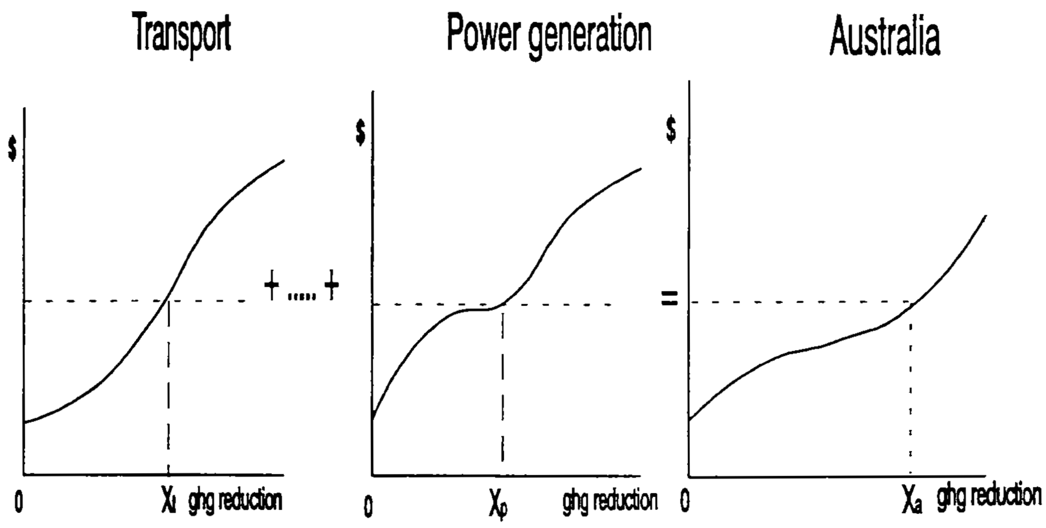
If the target reduction in greenhouse gas emissions in figure 6 is around 4.5 tonnes, the cost minimising combination of the two instruments may be identified by tracing vertically from 4.5 tonnes on the horizontal axis to the composite marginal cost curve, and then horizontally to the individual marginal cost curves. No matter how the target is altered within the range covered by this simple example, equalising the marginal cost will achieve the lowest total cost. It is important to note that this simple example assumes no interaction between the two instruments.

The marginal cost framework can be extended to include as many instruments as required to estimate the marginal cost curve for emissions abatement from the transport sector. Because curves based on costs in other sectors can also be added, this approach provides a very flexible analytical tool.

(iii) National and Global Greenhouse Reductions

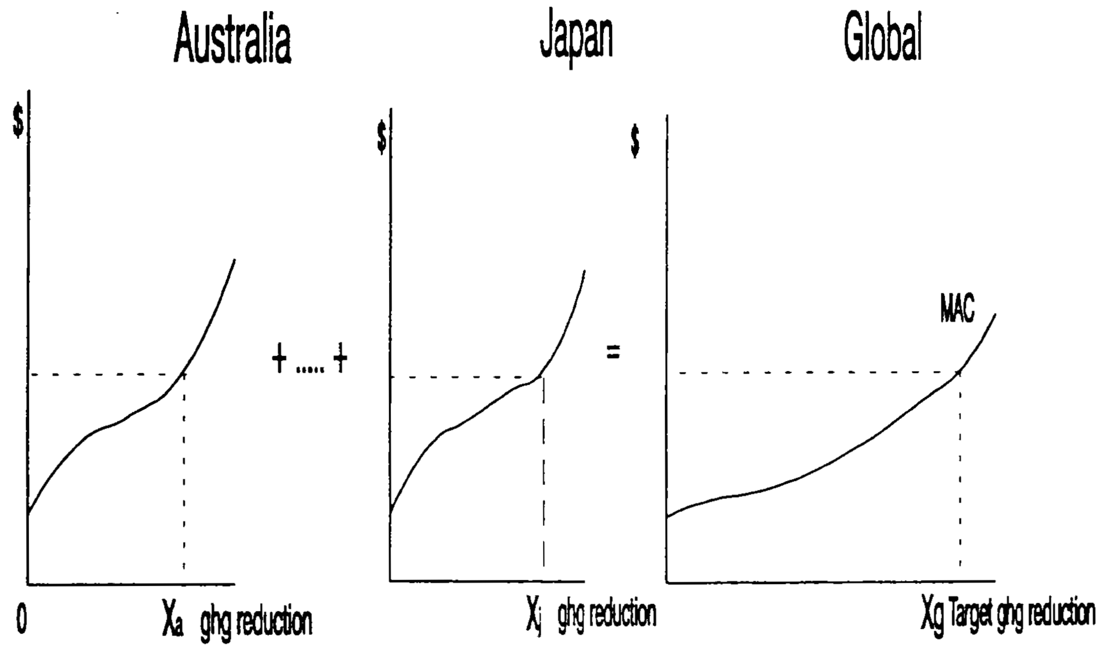
The marginal cost of emissions reduction from other sectors could be added and summed to the 'transport' curve to produce a national greenhouse gas reduction marginal cost curve (figure 7). The cost minimising combination of instruments for achieving a national target for greenhouse emissions reduction can be identified and attributed to policy instruments in each sector.

Figure 7 Marginal Cost of Reducing Australian Greenhouse Emissions



National marginal cost curves derived for individual countries could also be summed to produce a global marginal cost curve for greenhouse emissions reduction as depicted in figure 8. Each country could be allocated responsibility for reducing emissions consistent with meeting a global emissions reduction target. The apportionment to meet the global target would then be on the basis of least total global cost.

Figure 8 Marginal Cost of Reducing Global Greenhouse Emissions



The BTCE study in essence seeks to estimate marginal cost curves for a wide range of reduction levels. This approach will enable decision-makers to assess the costs of a range of emission reduction scenarios for transport activities.

But unless the marginal cost of abatement is derived for other economic activities (agriculture, industry and household energy use, power generation, etc), it will not be possible in practice to determine the optimal allocation of emission abatement responsibilities either between different countries or between different sectors of the Australian economy.

D. THE BTCE GREENHOUSE STUDY

(i) Contribution to Economic Research and the Policy Debate

The BTCE study will be unique in a number of respects. It will provide Australian decision-makers with information on the economic costs of a range of measures to reduce greenhouse gases in transport. Use of marginal cost analysis will permit the choice of least cost sets of instruments.

Greenhouse gases are not being analysed in isolation in the study. The analysis will include other related social benefits and costs such as changes in noise or noxious emissions associated with instruments designed to reduce greenhouse emissions.

Stated choice experiments will be used to enrich observed (revealed preference) data to permit assessment of products or instruments that are not currently available or used. For example, it will be possible to assess the likely acceptance of alternative fuels or road pricing. An additional benefit of the study is that hitherto unavailable data in the freight and urban passenger sectors will be generated for major capital cities.

(ii) Objectives and Scope

It is the primary objective of the BTCE study to identify the least cost combination of measures that could be employed to reduce greenhouse gas emissions in the Australian transport sector. As discussed above, the marginal abatement benefit is unknown and the study is directed at identifying the most cost effective measures rather than determining an optimal level of greenhouse gas emission reduction. To allow policy makers to assess the full implications of implementing various policy instruments, the study will identify distributional effects. Transfer payments, sources of funding of subsidies, and the socio-economic groups affected will be given special attention.

The IPT envisages a permanent reduction in the level of greenhouse emissions. Both long and short term reduction measures will be analysed over the period 2000 to 2015 at five year intervals. 1996 will be used as the first practicable year of implementation. The cost of abatement measures for each of the benchmark years 2000, 2005, 2010 and 2015 will be expressed in net present value (NPV)[5] as at 1996 to permit comparison between measures. Total costs (and cost savings) will be estimated for each year from the date of implementation of the instrument.

The BTCE study will include analysis of the interactions between different greenhouse reduction measures. The effectiveness of one policy instrument may be influenced by another instrument - either in a complementary or opposite manner. For example, if speed restrictions reduce usage of fuel, a carbon tax will be able to operate only on the lower level of fuel already being used. Conceptually, this involves checking the extent to which marginal cost curves are horizontally additive with each other. The study of the interrelationships between urban form, transport and the environment will form a major aspect of this work.

A major consultancy has been let to the Institute of Transport Studies (ITS) at the University of Sydney to assist in the urban passenger transport segment of the project (appendix 2). Travel behaviour information will be obtained by means of surveys in 6 capital cities (Sydney, Brisbane, Melbourne, Adelaide, Perth and Canberra). About 3500 households will be interviewed by telephone. Approximately 1200 interviews, drawn from sample households stratified by location and socio-demographic characteristics, will be conducted face to face.

A major aspect of the survey will be a number of stated choice experiments designed to yield stated preference data. These data will be used to 'enrich' observed (ie revealed preference) data. For example, the results of stated choice experiments can be used to estimate likely responses to the introduction of new travel alternatives or new options within existing travel modes. Examples of policy instruments for which such experiments can be used include the use of alternative fuels, new light rail systems, and congestion pricing.

Consumer responses to measures not included in the ITS survey, many of which are applicable to the transport sector as a whole, will be undertaken within the BTCE Greenhouse Unit. These may include direct regulation of vehicle technology and emissions equipment, infrastructure investment, education campaigns, and use of tradeable emissions permits.

There is limited potential for emissions reduction in non-urban areas through modal change such as a switch from car travel to bus or train travel. For example, the most energy-intensive mode per passenger kilometre, air transport, is not likely to be replaced by other modes for the trip lengths involved. The OECD (1993) states that for Australia:

> "...Modal substitution may also be difficult in non-urban areas. The study finds that the least energy-intensive mode is the bus, which achieves higher load factors and faces better traffic conditions than in urban areas. The most energy-intensive mode is air transport, which

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5 NPV refers to the discounted value of the future stream of costs (net of benefits) of reducing emissions

is not likely to be replaced by other modes for the trip lengths involved. A major source of emission reduction will be technological developments in fuel economy." p223.

An analysis by the VFT Joint Venture (1990) on the emission impact of the erstwhile proposed VFT between Melbourne, Canberra and Sydney, found that the introduction of the Very Fast Train (VFT) would increase carbon dioxide emissions. The findings were based on the assumption that there is limited scope for substitution away from the more intensive carbon dioxide emitting mode of air transport, and considerable scope for substitution away from bus transport, the mode which emits the least carbon dioxide per passenger kilometre. Considerable emissions were also assumed to be generated from travel due to the novelty of the VFT itself. Nevertheless, the BTCE proposes to examine the potential for modal shifts in two major inter-State corridors, with a view to extrapolating the results to other areas of Australia.

Instruments that can be applied specifically to freight transport include introduction of fuel saving devices such as aerodynamic streamlining; investment in rail and sea infrastructure to encourage switching to more fuel efficient modes of freight transport; and incentives to encourage switching to alternative fuel use in freight vehicles. The possibility of freight vehicles adopting fuel-saving devices and technology, or substituting to more energy efficient fuel, and their costs, will be estimated. A consultancy is to be commissioned to assist in the collection of data.

Although they have not traditionally been considered to be part of the transport sector, urban and non-urban pipelines will be considered as part of the total transport task. In the absence of pipelines (including conveyor belts in some areas), freight such as oil, gas, coal or iron ore slurry, water and sewage would need to be transported by other modes. Except where total gravity feed is possible, pipeline transport consumes energy through pumping.

It is not entirely clear at this stage how emissions resulting from inwards or outwards international voyages should be attributed to Australia. Nevertheless, a number of instruments for reducing emissions from bunker fuels will be analysed.

Measures that reduce greenhouse gas emissions are also likely to affect the level of other transport externalities. A fuel tax, for example, could be expected to reduce greenhouse gases by reducing the amount of fuel used. If the volume of traffic is simultaneously reduced, there may be an associated reduction in noise, local pollution, traffic accidents and congestion.

Figure 9 Net Marginal Cost of Reducing Greenhouse Emissions

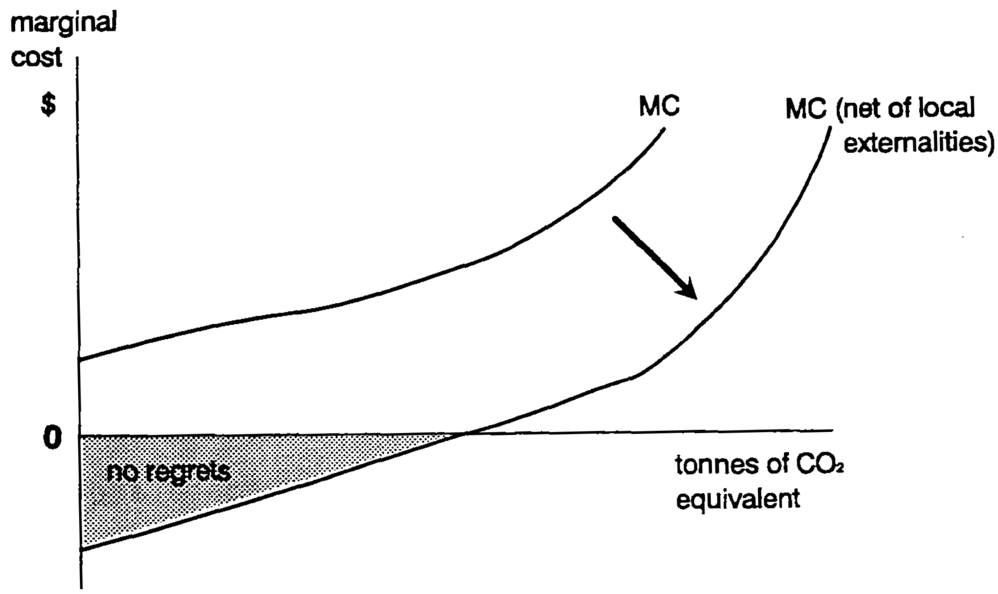

Figure 9 depicts the effect of taking into account associated transport externalities. The marginal cost curve derived for a specific greenhouse reduction measure, for example a fuel tax, shifts downward to indicate a lower net cost. Where the (net) marginal cost curve falls below or on the horizontal axis, the net additional cost to the community of reducing greenhouse gases is negative or zero. Measures that involve net negative or zero additional costs to the community are termed 'no regrets' measures because they represent effectively costless ways of reducing greenhouse emissions.

A separate BTCE project is currently estimating the costs of four transport externalities in Australian cities (see Part E below on other externalities).

(iii) Selection of Measures

Ideally, as wide as possible a selection of feasible abatement measures should be costed. A wide selection will afford policy makers a better information base on which to take decisions.

Three major criteria have been identified as a basis for selecting instruments. The perceived effectiveness of the instrument in terms of its capacity to reduce emissions is an important criterion because the ultimate aim of the study is to find the cheapest way to a achieve a given reduction in emissions. Direct regulation, for example, is likely to give a greater and more certain outcome than instruments which rely solely on moral suasion.

Instruments which have an economy-wide impact on a particular emission source or type of pollution have the advantage of being both well targeted and less distortionary. For example, an emissions tax that can be applied to all sources of greenhouse gases according to their global warming potential is likely to have a less distorting impact than a tax on a particular fuel.

Third, instruments which offer transport users a degree of choice as to how they respond to the particular measure are more likely to gain government and community support. For example, the imposition of pollution taxes would allow people to choose whether they will reduce pollution, or continue to pollute but pay for doing so. A preliminary list of measures to be costed is at appendix 1.

It should be noted that distributional or equity considerations are not in themselves a selection criterion. Equity aspects will nevertheless be assessed for all instruments.

(iv) Cost Estimates for Greenhouse Abatement Measures

As a first stage, total and marginal economic costs are to be estimated.

Most studies of the greenhouse phenomenon include only directly observable 'accounting' variables such as fuel usage or vehicle operating costs. Although this approach is often unavoidable due to lack of data, it can provide only a distorted view of the relative efficiency of various measures.

Studies that include only 'accounting variables' fail to provide estimates of economic effects such as losses or gains in consumer and producer surplus. By excluding measures of consumer surplus, such studies ignore the relative utility that consumers attach to various forms of transport. Results limited to 'accounting' variables will thus not provide decision-makers with a complete picture of the costs borne by those affected.

Measures that involve large losses in consumer surplus are likely to be less acceptable to the community. For example, restrictions on parking in the CBD of a major city may impose very great costs (both psychological and financial) on handicapped people who require access. A less dramatic, but equally pertinent example, might include couriers or providers of essential services who may require easy access to all areas of the CBD but are denied it.

Comparison of abatement measures in different economic sectors would also not be valid if only 'accounting' variables were included. A consumer may not be prepared to reduce the use of a car but would be relatively happy to reduce the amount of electricity consumed in the household, for instance. Because consumer surplus is excluded, this preference is not captured.

The BTCE study will therefore seek where practicable to include all relevant economic costs. Direct costs of labour and materials such as fuel saved will be included, as well as capital costs and losses or gains in consumer and producer surplus. Transfer payments in the form of taxes and subsidies are excluded from the analysis of costs, but will be taken into account when the distributional impact of the various measures is examined.

(v) Finding the Least Cost Combination of Instruments

In the discussion so far it has been assumed implicitly assumed that the costs of instruments are independent of each other, and that they have certain desirable mathematical properties (continuous, non-decreasing, etc). In practice, we can be fairly sure that these conditions will not hold, and that it will not be possible to identify the least cost combination of strategies simply by horizontal summation of marginal cost curves[6]. It will, therefore, be necessary to use some form of numerical optimisation technique to search for the least cost combination over the space of all possible combinations and levels of the instruments.

The main difficulty in such an optimisation exercise is to take account of the interactions between instruments.

As part of a consultancy to the Institute of Transport Studies, a sophisticated model of urban passenger travel behaviour is being developed. The model will simulate households' and people's choices of work and residential location, type and number of vehicles, and commuting and non-commuting travel preferences. Using the ITS/BTCE model, a wide range of instruments which affect choices can be modelled, either singly or in combination, and the travel consequences (most importantly, costs and emission reductions) determined.

Equivalent procedures will be required to take account of the interactions among the freight and non-urban transport instruments, and between these and 'urban passenger' instruments. However, the details are yet to be worked out.

E. OTHER EXTERNALITIES

In order to improve understanding of the costs involved in the Australian transport sector, the BTCE is also engaged in a major study of transport externalities. This study will provide the first systematic costings of the impacts of noise, noxious vehicle emissions, accidents and congestion in major Australian cities. Estimating the value of these externalities will involve significant conceptual difficulties.

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6 It will still be the case that, once the least cost combination of instruments is found, the rate of variation of this cost with the level of abatement will be same for all continuously variable instruments in the set. But, except in very simple cases, this property cannot be used to find the least cost set.

(i) Congestion

Congestion may be estimated with the aid of urban traffic models as the difference in travel time (TT) and vehicle operating costs (VOC) under current and hypothetical uncongested conditions. Three different estimates of TT and VOC under such hypothetical conditions are possible:

(i) The estimates could be based on current traffic patterns but with traffic moving at free flow speeds, unhindered by other road users.

(ii) The estimates could be based on road users making their current trips, but using preferred routes. The assumption here is that, under current traffic patterns, routes are selected, in part, to avoid congestion. Without congestion, traffic would not only flow faster but, in general, would choose shorter routes. TT and VOC would therefore be less than under (i).

(iii) Finally, the estimates could be based on road users making their preferred trips. Congestion not only influences route selection, but also the choice of destination and, indeed, whether to travel. Some trips are abandoned altogether. For others, closer or more convenient destinations are substituted for those which might otherwise have been preferred. Without congestion, total travel and the corresponding TT and VOC would be higher than in (ii), and could exceed the levels in (i) or, conceivably, even the levels under current congested conditions. However, the additional costs would be more than compensated by the benefit derived from the additional travel.

Estimates of congestion costs based on (i) and (ii) are straightforward. Those based on (i) would be less than those based on (ii).

Use of (iii) as a base for congestion costing raises the issue of the consumer surplus lost when travel is suppressed by congestion. This goes beyond the simple use of TT and VOC as measures of congestion costs. The simple trip generation mechanisms in current urban traffic models are unlikely to be adequate for such analyses.

Congestion costing also depends on assumptions about the value of travel time savings, and these must take account of both travel purpose and trip length.

(ii) Accidents

Accident costs are based on statistics of accidents reported to the police and on estimates of unreported accidents obtained from studies of insurance records. Unit accident costs are available from recent work by the Australian Road Research Board (ARRB).

(iii) Noise

Noise exposure near urban arterial roads can be estimated for the levels of traffic predicted by traffic models, although it is not clear whether commonly used measures of noise exposure adequately describe the impact on people. One indicator of the cost of this impact is the effect of noise on property values, which can be measured with aid of noise depreciation indices. Such indices typically suggest that residential property values are reduced by between 0.4 and 1.0 per cent per decibel above a threshold noise level.

(iv) Noxious Vehicle Emissions

Estimates of the costs of (non-greenhouse gas) vehicle emissions are particularly difficult as there is a long chain of complex interactions between vehicle emissions and their eventual impacts (on health, for example). Substantial uncertainties in the areas of motor engineering, atmospheric chemistry, meteorology and human physiology limit our understanding of the effects - even prior to the uncertainties involved in any economic questions of costing.

Nevertheless, estimates of the consequences of greenhouse gas reduction measures on the *production* of primary noxious emissions by traffic can be made using known emission rates. These can be compared with air quality measures and preliminary estimates associated health effects and costs. It should be possible to obtain at least order of magnitude estimates (or upper or lower bounds) to the contribution of local air quality changes to the costs of greenhouse gas reduction strategies.

A 'back-of-the-envelope' estimate using overseas findings applied to Australian transport data was published in the 1993 September quarter issue of Transport and Communications *Indicators* (BTCE 1993b). As shown in table 6, drivers in urban areas are, on average, likely to impose about a 10 cent cost on to the community at large for every kilometre travelled.

Table 6 Indicative Costs of Urban Transport Externalities

Indicator	Externality				
	Noise	Noxious Emissions	Accidents[a]	Congestion	Total
Approx.unit costs Melb. or Sydney (cents per vkm)	0.3[b]	0.7[b]	1.2[c]	8[d]	about 10
Per cent of GDP					
Selected OECD countries[e]	0.06-0.21	0.05-0.34	0.36-0.55	0.90-3.20	1.6-4.2
Australia[f]	0.11	0.21	0.43	1.06	1.8
Share of costs (per cent of total)	6	12	24	59	100

a The external component of urban accident costs is assumed to be 21 per cent of total national accident costs. This is obtained by assuming that urban accidents account for 70 per cent of total accident costs and, following Bouladon (1991), that 30 per cent of accident costs are borne externally.
b US unit costs used by Inter-State Commission (1990) - weighted average across vehicle types.
c External costs of urban accidents divided by total urban travel.
d Commeignes' (1992) estimate for Sydney divided by total urban travel in Sydney.
e Estimates, between 1981 and 1991, using a wide variety of techniques, reported by the OECD for France, Germany, Netherlands, United Kingdom and the United States.
f Estimates between 1988 and 1990. Noise and emissions estimates are from Inter-State Commission (1990) which applied US unit costs directly to Australian traffic volumes. Accident costs are based on BTCE (1992). Costs of congestion are assumed to be twice Commeignes' (1992) estimate for Sydney.

Source: BTCE estimates based on Inter-State Commission (1990), Quinet (1990), Bouladon (1991), BTCE (1992), and Commeignes (1992).

F. INITIAL RESULTS

Three 'pilot studies' were undertaken in the latter half of 1993 in order to test both the methodology proposed, and to help identify data needs and common information needs. For example, the studies confirmed a need for standardised base case emission estimates and projections. The results reported below are therefore presented as initial, 'back-of-the-envelope' estimates.

(i) Impact on Emissions of a Newer Vehicle Fleet

In 1991 the Australian passenger fleet consisted of 8 million cars with an average age of 9.7 years and an average fuel efficiency of 11.4 litres per 100 km (ABS, 1993). This made it one of the oldest and least fuel efficient in the OECD.

Two changes which could improve the efficiency of the Australian passenger fleet were investigated. The first was an increase in the scrappage rate (ie the proportion of cars registered in one year which were not registered in the subsequent year). The second was an improvement in the fuel efficiency of new registrations.

To isolate the effect of an increase in the scrappage rate, a base case was established with the following assumptions. The annual scrappage rate from 1992 to 2015 was assumed to be the same as the average annual rate of 3.74 per cent from 1990 to 1992[7]. The annual rate of increase in new registrations from 1992 to 2015 was assumed to be the same as the average annual rate of 3.48 per cent in recent years. It was assumed that there would be no technological change after 1990. The carbon dioxide emissions from the Australian fleet in 2015 were forecast to be 57 mega tonnes.

An increase in the scrappage rate to five per cent accompanied by a compensating increase in new registrations (to keep the fleet size in any year unchanged) would result in a younger, more efficient fleet. However, the effect that this would have on carbon dioxide emissions depends on the driving patterns of the owners of the additional new registrations.

If new cars from 1995 to 2015 are driven the same number of kilometres that new cars averaged in 1988, the model predicts an increase in carbon dioxide emissions in 2015 to 61 mega tonnes. On the other hand, if the new cars are driven, on average, the same number of kilometres as the older cars they replaced, the model predicts a slight decrease in carbon dioxide emissions below 57 mega tonnes[8].

The increase in the scrappage rate from 3.47 per cent to 5.0 per cent implies that an additional 3.3 million cars would be scrapped. The net present value of these vehicles is estimated conservatively to be $4.6 billion. This cost, along with the indeterminate effect any increase in the scrappage rate would have on emissions, suggests that a policy to encourage an increase in the scrappage rate may result in no net emissions reduction.

Improvements in the fuel efficiency of new registrations were investigated by relaxing the assumption that there is no technological improvement after 1990. If the average fuel efficiency of new registrations improved from 10.47 litres per 100 kilometres in 1990 to 8.19 litres per 100 kilometres in 1996, 7.26 litres per 100 kilometres in 2000 and in 2005 to 6.35 litres per 100 kilometres there would be a reduction in fuel used. Assuming no change in driving patterns (due to savings from reduced fuel usage) this would result in a reduction in carbon dioxide emissions in 2015 to 38 mega

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7 Based on data from ABS Motor Vehicle Registrations Australia, 1987/88 to 1991/92 (ABS, 1989 to 1993).

8 In 1988, new cars were driven, on average, 24,500 kilometres, and 20 year old cars, on average, 10,000 kilometres (ABS, 1990).

tonnes; compared with the base case projection of 57 mega tonnes.

(ii) Tax on CO_2 Emissions of Freight Transport

Another instrument examined was a tax on carbon dioxide emissions from the freight transport sector, and the impact the tax has on carbon dioxide emissions in the year 2005. As about 80 per cent of emissions from freight vehicles relate to land transport, this study focused on land and rail freight in Australia.

The objective of the study was to obtain some preliminary estimates of the total costs of introducing a carbon dioxide tax on fuel consumed. The tax was assumed to be introduced in 1996, and the costs estimated for 1996 to 2005 and discounted to the current year in 1993. To obtain a schedule of costs and emission reduction levels, the tax rate was varied at seven increments of five cents per litre for diesel. The schedule of marginal costs for each level of emission reduction was obtained by taking the change in total costs for a change in emission reduction.

In theory, the tax would be imposed on the amount of carbon dioxide emitted. In practice, this is difficult to do with moving vehicles. But fuel consumption is a good proxy for carbon dioxide emissions because there is a scientific relationship between fuel used and the carbon dioxide emitted.

Three types of fuel are currently used by freight vehicles: diesel, petrol and liquefied petroleum gas. In 1990-91, diesel constituted about 60 per cent of total fuel used by freight vehicles (ABS, 1993).

Each fuel type has a different energy content and carbon dioxide conversion factor. The tax was based on diesel. To calculate the tax on other fuels, the diesel tax rate was scaled in proportion to the grams of carbon dioxide emitted per litre, relative to that of diesel. It was assumed that the fuel tax was introduced in addition to the current fuel excise of 29.57 cents per litre, as at 1 November 1993.

Three types of costs were considered in this study:

- Set-up and Administrative costs

  It was assumed that the tax is collected at the same source as the current fuel excise. Hence only small set-up and administrative costs are assumed ($3 million for the set-up costs in 1996 and additional $1 million for administration each year).

- Change in Consumer Surplus

  It was assumed that the fuel tax is fully passed on to users of freight transport, as demand for fuel used by freight vehicles is derived from demand for freight. An increase in fuel costs would mean that road freight rates would rise. The extent of the increase depends on the proportion of freight costs represented by fuel. On the basis of informal work done within the BTCE, this was assumed to be about 13 per cent.

The increase in freight rates resulted in a loss in welfare or consumer surplus. Only the change in consumer welfare net of transfer payments (ie. tax payments) was considered.

To calculate changes in consumer surplus, own price elasticities of demand for freight were used. These were 'borrowed' from estimates in other studies. Estimates of own price elasticities of -0.39 (short run) and -0.8 (long run) were used (Luk and Hepburn, 1993). Estimates of cross-price elasticities between road and rail of 0.2 are based on estimates from Oum, Waters and Yong (1990); estimates originally intended for use in the BTCE Sydney-Brisbane corridor study.

- Reduction in noise pollution

A fuel tax may result in a reduction of vehicle kilometres travelled by freight vehicles, thus reducing the noise pollution caused by truck vehicles. Different measures are used for the costs of urban and non-urban noise pollution, with the cost being much higher for urban transport. Unit costs of 2.17 cents and 7.055 cents per kilometre were assumed for non-urban and urban areas respectively (Inter-State Commission, 1990). The cost savings from reduction of noise pollution offset the administration and set-up costs, and the loss in consumer welfare.

The results of the study show that the total costs of the tax, (present value of set-up and administration costs, change in consumer surpluses, reduction in noise and pollution costs), for all levels of tax rates, are low relative to the tax revenue collected. It should be noted that the costs relating to the adoption of fuel-saving devices are not included in the total costs estimated, as this information was not available. Imposition of the tax did not result in any major shift from road freight to rail. This is because the tax is applied to diesel for both road and rail and because price is not the most significant determinant of road-rail competition along freight corridors.

The preliminary analysis also shows that to achieve the 1988 carbon dioxide emission level for the freight sector in the year 2005, would require a carbon dioxide tax on diesel of 35 cents per litre of fuel. To achieve a reduction in 2005 for the freight sector of 20 per cent below its 1988 level, a tax level of about 70 cents per litre would be required. The large amount of tax revenue that can be collected from the tax gives rise to equity issues, and the question of how the revenue should be used.

(iii) Carbon Sequestration

An alternative to estimating costs of reducing emissions is to calculate a 'clean-up' or 'control' cost. The 'control' cost of removing carbon dioxide emissions provides a benchmark opportunity cost against which emission reduction measures can be compared.

Carbon dioxide could be reclaimed in a number of ways. Technological options include liquefication or pumping under the sea. Planting trees is an alternative based on current technology. Afforestation will not reduce the level of carbon dioxide emissions from transport, but it can absorb some of the carbon dioxide and hence carbon emitted from transport.

Trees are the second largest carbon dioxide sink after oceans. Through photosynthesis, carbon dioxide is absorbed from the atmosphere and converted into carbon, which is stored mainly as wood. The rate at which a forest absorbs the carbon dioxide depends on the growth rate of the particular forest. A faster growing forest absorbs carbon dioxide quicker than a slower growing forest.

A model of forest growth taken from Richards (1969) and used by the Bureau of Resource Sciences as a carbon sequestration model was used. The growth function is described in equation (1).

(1) $W = A\exp(-b\exp(-kt))$

(2) $b = -\ln(s/A)$

(3) $k = (\ln b)/n$

where W is the total amount of carbon sequestered at any time (t); A is the maximum amount of carbon which can be sequestered over the life of the forest (ie the asymptotic value of W); and b and k are constants. s depicts the amount of carbon initially stored in the seedlings, and n is the year of maximum growth (ie the inflection point of the curve).

ABARE projections of fuel use in the total transport sector and the road transport sector were used to calculate carbon dioxide emissions for the 'business as usual' scenario. In order to reduce emissions by 45 mega tonnes in the year 2005, the model predicts that a plantation size of 639,300 hectares would need to be established in 1996. This assumes a 40 year growth cycle to maturity, and a maximum carbon storage level of 390 tonnes per hectare. For the total transport sector, a target of 56.5 mega tonnes would require a plantation of 919,500 hectares.

Australian plantations currently occupy 1,041,000 hectares (ABARE, 1992). A 639 300 hectare forest would involve increasing the current plantation size by 61 per cent. Most of the suitable areas for a plantation are currently used for agricultural purposes. The Resource Assessment Commission (RAC, 1992a) estimates the availability of between 2.87 mega hectares and 3.04 mega hectares of suitable land close to a processing site and with a low intensity of agricultural use.

By the year 2020 a 639,300 hectares plantation would be supplying the wood industry with an additional 155 million m^3 of timber. At this time, ABARE (1989) projects a domestic shortfall in sawlog timber to be only 32 000 m^3. A 639,300 hectare plantation would thus make Australia more than self-sufficient in wood production.

The major question is what to do with the standing wood once a forest reaches maturity. A mature forest will only absorb very small amounts of carbon dioxide and will eventually emit it back into the atmosphere as the leaves and stems decompose or burn. In this sense, standing forests are only a temporary storage for the carbon. Unless treated or protected from the weather, wood products will also decompose and re-emit carbon back into the atmosphere as carbon dioxide. Paper products have a half-life of only 1 to 5 years, while treated timber used in housing structures and furniture has a half-life ranging between 10 to 100 years (Barson & Gifford, 1989). Wood treatment techniques can increase storage lives.

The cost of establishing and harvesting a plantation has been estimated by the BTCE to be $2,908 per hectare for a hardwood plantation, and $2,500 per hectare for a softwood plantation. These estimates include the purchase price of the land, and a combination of estimates undertaken by the Resource Assessment Commission of various plantations (RAC, 1992a).

For a 639,300 hectare plantation, the cost would be approximately $1.86 billion for hardwood and $1.6 billion for softwood. The cost per tonne of carbon dioxide sequestered would be $2.69 for hardwood and $2.31 for softwoods[9]. The cost per vehicle in 1996 would thus be $139 for softwood and $162 for hardwood. The equivalent fuel costs for the period 1996 to 2005 would be approximately 6 to 10 cents per litre based on average fuel use projections (ABARE, 1993).

Planting costs could be offset to a certain extent through the sale of the timber. Assuming an average volume of merchantable wood added to a hectare over a year to be 7.7 m^3/hectares/yr for hardwood, at a price of $15.36 per m^3 of standing timber, a revenue of $2,721 per hectare of hardwood plantation is calculated.

This monetary value does not take into account other benefits of planting trees, such as improved soil and water quality and reduced land degradation. It is nevertheless difficult to place a monetary value on the intrinsic and non-marketable benefits of a forest.

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9 Assumes 692 Mt of carbon dioxide is absorbed over the life of the plantation (ABARE, 1993).

PROPOSED POLICY INSTRUMENTS FOR COSTING

	TYPE OF INSTRUMENT	COMMENTS
	MARKET BASED	
•	**Taxes and charges**	
1	Road user charges	Not well targeted to the source of emissions unless levied by vehicle type, km travelled, fuel type, etc.
2	Carbon tax	A broad-based measure which reflects the cost of CO_2 emissions if levied according to the carbon coefficient of the fuel. CO_2 emitters pay and make transfers to government. Response to tax, hence total GHG reduction, depends on the elasticity of demand.
3	Differential registration charges levied on km travelled or fuel type	Could be designed to encourage purchase of less polluting vehicles/discourage over-use of vehicle/lower emitting fuels. Complex to administer.
4	Differential sales tax	Sales tax could be lower for less polluting cars, eg by size, power, fuel type/economy but would not encourage lower emissions in construction of cars, eg production processes or raw materials used. Complex to administer.
5	Increase fuel excise	Similar to a carbon tax but does not encourage use of lower emitting fuels. The excise status of exempt fuels such as LPG (or lower taxed such as fuel oil), as well as exempt sectors such as mining and farming, need to be considered.
6	Remove exemption from fuel excise of Commonwealth agencies*	Efficient in as much at it removes a distortion. Cost pressures could lead to downsizing of government fleets and management improvements. Alternative forms of transport/reduced travel could result in lower fuel use and emissions reduction from fleet vehicles.
7	Increase parking charges eg CBD	Do not target vehicles according to emissions levels. Effectiveness depends on enforcement.
8	Modify fringe benefits tax, allowable company car deductions, etc.	Company taxes, as well as registration charges and sales tax, could be used to influence discetionary company car provision & use. In 1992 just over 50 per cent of all new passenger vehicles were for government and business use. The implications for emissions from 'over use' of 'large' company cars, as well as for the composition of the second hand car market (most 'fleet' vehicles are sold after about 2 years), is important.
•	**Subsidies:** (Could generally achieve reductions efficiently but violate the 'polluter pays' principle. To remain efficient subsidies would need to vary as relative input and output prices charges. As with taxes they could not guarantee attainment of a target. Subsidies may reduce incentive to adopt cleaner technologies; impact adversely on other sectors; and/or inhibit modal/fuel shifts. The source of revenue is an issue, particularly regarding distribution effects).	

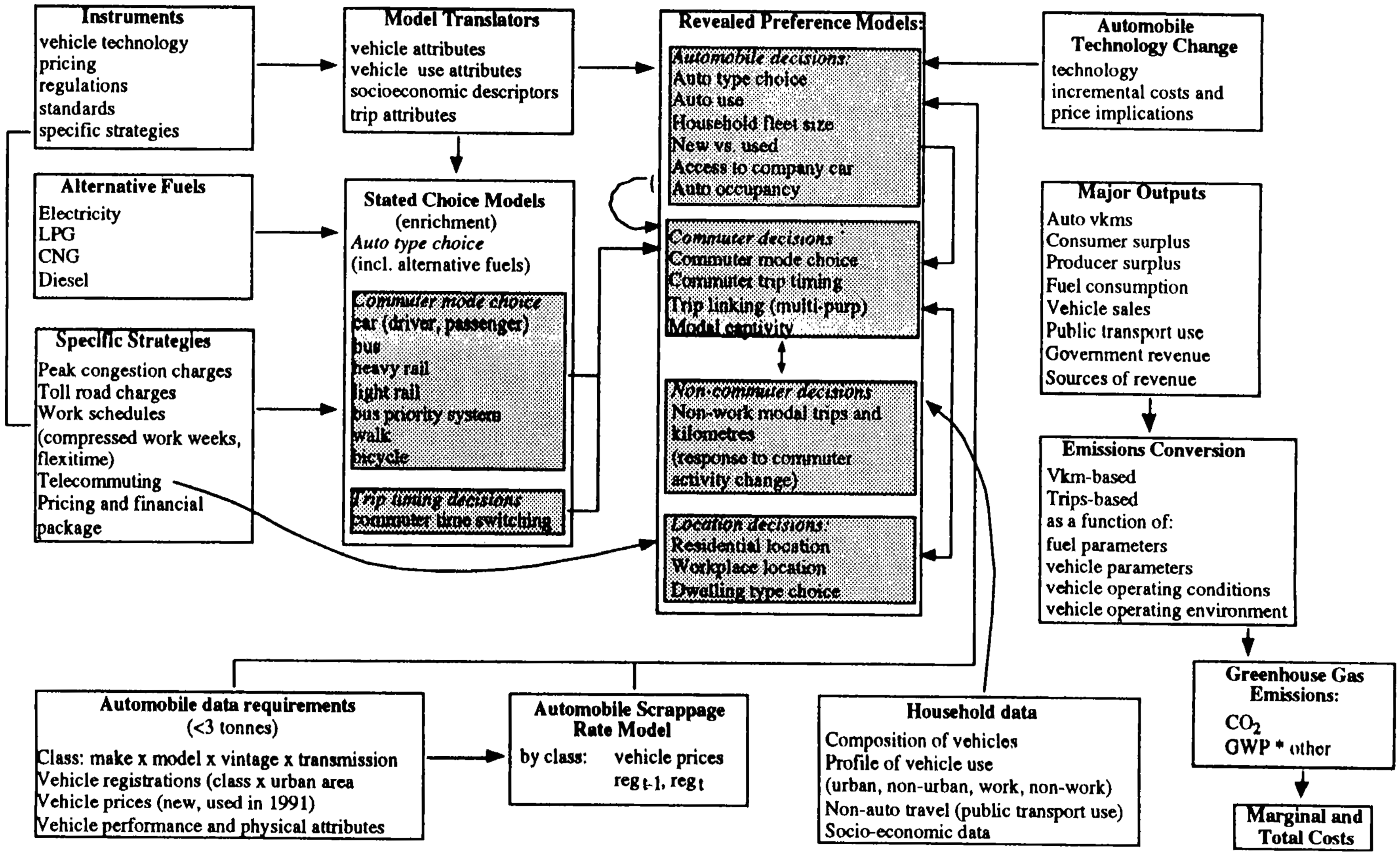
9	Subsidise efficient technologies	Possible case for compensating industry for adjustment costs relating to new regulatory requirements.
10	Subsidise public transport	Could encourage modal shift, but public transport could be less efficient than cars during off peak periods.
11	Subsidise alternative fuel conversion	Could encourage conversion to lower emitting fuel use.
12	Subsidise oil ind. to reformulate fuels	As above
13	Subsidise solar car technology	As above.
14	Subsidise electric car technology	As above. GHG depend on electricity source.
15	Ride sharing incentives	As above. Could be difficult to administer and monitor. May preclude flexible working hours.
16	Funding for sinks eg forests	Could be used in conjunction with a carbon tax. Preliminary estimates indicate that around 1 million hectares of trees would need to be planted to absorb CO_2 from 75 per cent of all road vehicles.
17	Subsidise early scrapping (eg through registration charges)	The emissions impact of a newer vehicle fleet is indeterminate until the likely effect on total vehicle kilometres travelled has been assessed (people might drive newer vehicles more than older vehicles).
•	**Property rights**	
18	Tradeable permits	An economically efficient instrument. The quantity of emissions is chosen. Monitoring could be difficult. Greenhouse gas emitters bear the abatement cost; there are no transfers. Distribution effects depend on the initial permit allocation system.
REGULATIONS AND STANDARDS		
•	Regulate emissions	Efficient only if everyone faced the same cost of abatement, or were required to reduce emissions according to individual abatement cost functions (unrealistic). Specifying allowable discharge rates ensures the target is achieved if monitoring is effective. Users bear the abatement costs; there are no transfers.
19	Compulsory vehicle checks of emissions equipment	Could be an effective way of regulating emissions if done in conjunction with registration renewal.
20	Standards for fuel volatility	Could impose excessive costs on refining industry.
•	Regulate industry process/ equipment	Could be effective if vehicle process and equipment techniques are regulated to ensure maximum discharge rates.
21	Regulate on-board catalytic converters	Could be effective but would impose higher costs on people with older cars facing higher modification costs.

22	Regulate/set standards for on-board diagnostic systems	As above.
23	Standards for emission control equipment	As above.
24	Engine maintenance standards	Effective if checked along with registration renewal.
25	Spot emissions testing	Difficult to administer. Could be feasible with the right technology; in conjunction with standards. Note FORS work.
26	Regulate max. age of vehicles	Equity issues involved - poorer people may have older cars.
•	**Other regulation**	
27	Regulate car pooling	Hard to administer and draconian. Imposes excessive costs on those who place high value on driving alone.
28	Require fuel producers or consumers to recover carbon	Could be done through tree planting with costs passed on to consumers.
29	Regulate lower speed limits/ limiters	
30	restrict vehicle access to CBD	Could impose excessive costs on some. May not reduce emissions if people travel further to park and ride. Reduced congestion could reduce emissions.
PLANNING		
31	Higher density urban form eg through stamp duty/ development cost recovery	Could have longer term impact on emissions but difficult to assess.
32	Guidelines for proximity of dwellings, shops and office space	As above.
33	Develop and incorporate into housing planning codes principles to reduce fossil fuel use from transport*	As above.
34	Integrate land-use and transport planning*	As above.

35	Traffic m'ment schemes eg signal-linking	Impact on emissions uncertain. Could be high infrastructure cost.
36	Route guidance equip.	As above.
37	Reduce parking supply	May not reduce emissions if people travel further to park. Could impose high costs in terms of time and frustration.
38	Encourage tele-commuting	Potential to be effective if technology widely available. Could impose costs in terms of isolation; and/or encourage more less efficient (home) energy use.
EDUCATION/ INFORMATION DISSEMINATION/ SUASION: (Lack of information is often cited as a cause of inefficient energy use. Effectiveness of these instruments depends on the extent of ignorance, receptiveness to suasion and costs of information dissemination/education).		
39	Community education program to walk/cycle*	As above. NB. public transport campaigns underway - monitor impact.
40	Vehicle labelling and publicity*	As above.
41	Info programs on good driving practices*	As above. Include information on tyres - inflation and friction. Examine effectiveness of similar campaigns, eg anti-smoking, 'slip-slop-slap', seat belts, Keep Australia Beautiful, etc.
42	Info programs on optimum speeds for lower emissions*	As above.
43	Info to encourage closer proximity of activities (eg between home, work, shopping)	As above.
44	Information on benefits of trip 'linking' and timing	As above.
45	Voluntary fuel economy program for all new vehicles sold*	As above.
46	Information on benefits of tele-commuting	As above.
47	Education on vehicle maintenance*	As above.

INFRASTRUCTURE		
48	Transit lanes	Could encourage car pooling/public transport.
49	New public transport infrastructure: roads/ (light) rail	Impact on emissions would depend on the extent of any modal shift; which in turn depends on relative prices.
50	Improve cycle/ walk facilities	Depends on extent of consumer take-up; could be done in conjunction with education program above.
51	Provide park-and-ride facilities	As above. Could be considered in conjunction with urban light rail system.
52	Speed humps	Impact uncertain as tendency for sudden braking at humps could increase emissions. High frustration cost.
53	Reduce road roughness	High infrastructure costs. Reportedly effective in reducing emissions, particularly for heavy vehicles.
54	Improve public transport services in high demand periods and routes*	Could result in a shift towards more efficient travel modes if the relative price signals encouraged this.
55	Improve road-rail linkages	Likely to result in less dependence on private cars and could reduce emissions.
56	Increase road capacity	Could be economic cost per emissions reduction. May encourage more travel where suppressed demand exists.
INSTITUTIONAL CHANGE		
57	Changes to vehicle fleet size/ composition/ leasing arrangement*	Could be considerable scope for cost savings and emissions reduction within the government vehicle fleet.
58	Develop guidelines and incentives to reduce the use of government vehicles*	As above.
59	Use alternative fuels in government. vehicles where practical*	As above. Could encourage the community to do likewise.
60	In reviews of public sector remuneration encourage reduced fuel use*	As above where choices of remuneration other than vehicle provision are available.

* Instruments contained in NGRS



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