The Cost of Australian Carbon Dioxide Abatement

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Abstract—The paper examines efficient means of abating the greenhouse effect by reducing the emissions of CO_2 It examines the generation of CO_2 emissions from fossil fuels in Australia, and analyses means to cut emissions from electricity generation and road transport. Finally, it calculates the cost in terms of growth forgone of measures to attain the Toronto targets for Australian electricity generation and road transport, using the ORANI multisectoral model.

1. THE TORONTO TARGET

Following concern at the increasing concentration of atmospheric CO_2 and the possibility that this would lead to global warming through the greenhouse effect, an international conference held in Toronto in 1988 proposed that all countries, including Australia, aim to cut their emissions of CO_2 associated with human activity to 80% of their 1988 levels by the year 2005. CRA Ltd. sponsored research which led to the Report summarized here. The Report focused on the direct emissions from energy use, although other activities, particularly land-use changes, will also generate emissions. As an examination of the feasibility and macro-economic effects of Australia's achieving the Toronto targets, the Report did not consider at length the benefits, if any, flowing from a postponement of global warming. In Nordhaus' (1990) words, the Report focused on the "abatement cost function" and ignored the problematic "greenhouse damage function".

In order to calculate the costs of the associated actions, we need projections of the outcomes without these actions. The base-case projections for the economy are discussed in Section 6, and the equivalent projections for the two sectors of electricity generation and use and road transport in Sections 4 and 5. Section 2 discusses the issues generally, and Section 3 outlines the patterns of Australian CO_2 emissions, identifying electricity generation and use and road transport as the two single largest sectors in terms of these emissions.

2. CARBON DIOXIDE—THE KEY GREENHOUSE GAS

The ultimate objective is not cutting CO_2 emissions at the individual country level or even globally, but rather to delay the onset of the greenhouse effect on climate and global warming. Focus on CO_2 is justified, however, as it is the most significant greenhouse gas, and others—notably methane (CH_4) and nitrous oxides—will be much more difficult to contain. Chlorofluorocarbons are already subject to international control.

2.1 World energy and carbon dioxide production

Per-capita emissions of CO_2, put Australia in a particularly unfavorable light. Australia has the fifth highest emission, at 3.9 t/y of carbon per capita, compared with a world average of 1.0 t/y. The high per-capita emission is partly accounted for by Australia's comparative advantage in energy-intensive industry, the abundant availability of coal, including brown coal with a high CO_2 emission rate, and our relatively small population. Australia's high proportion (41%) of energy supplied from coal is exceeded only by China's. Not surprisingly, both Australia and China have abundant coal reserves, with Australia one of the world's major exporters of coal (Marks, 1989).

Examining energy production on a per-capita basis can be highly misleading, especially since Australia is a major exporter of energy-intensive products: our emissions reflect the energy consumption of much of the rest of the world. Australia's share of the world production of CO_2 of 4.747 GtC/y is only 1.2% (Clarke, 1989); on this basis Australia's contribution is close to negligible. It is certainly negligible in the sense that unless Australia's policies can directly or indirectly affect CO_2 emissions from other countries, whether or not Australia is able to slow down its rate of CO_2 emissions will make a negligible difference to the world total and hence to the greenhouse effect. This emphasizes the obvious point that Australia alone can do little if anything to ameliorate the greenhouse effect. Nonetheless, to avoid being labeled a free-rider, it is necessary to examine whether and at what cost-effectiveness Australia can satisfy the Toronto target.

2.2 Abatement and adaptation strategies

It is possible to think about policies to deal with global warming in two distinct ways: abatement or adaptation. The first approach is exemplified by the Toronto Conference approach designed to mandate reductions in CO_2 emissions. The aim is to *prevent* the rise in global temperatures. The second strategy is to *adapt* to rising temperatures, supposing they eventuate.

It is a truism to state that the more certain and serious the possible outcome, and the cheaper and more efficacious the available policies, and the greater the likelihood that harm is irreversible, then the greater the preference for preventative policies over adaptive policies (Portney, 1989 p. 85). Clearly, some reductions in CO_2 emissions will come about relatively cheaply as a result of technical advances or cheapening renewable energy sources. These improvements should be adopted almost come what may: their adoption may have little to do with the greenhouse effect. Similarly, energy conservation which can be achieved readily with the simple provision of additional information should come about anyway, regardless of the greenhouse effect.

Once policies have been adopted at little cost, a more serious choice has to be made: should more expensive policies be adopted to switch from fossil fuels with high CO_2 emissions per unit of energy provided to those with less—for example, from brown coal to black coal and natural gas—or should fossil fuels generally be discouraged in favor of nuclear or renewable energy sources which may require large subsidies to compete with fossil fuels? Finally, large price rises for fossil-fuel-intensive final goods or fuel inputs may be required to induce consumption away from goods or services produced which require fossil fuels.

2.3 The simple economics of abatement policies

CO_2 emission abatement policies in response to the Toronto Conference recommendation could take several forms, namely,

- a mandated 20% reduction in CO_2 levels in each activity and in each region of Australia;

- as above, but with tradeable emission quotas so that the costs of reducing the output of CO_2 are equalized over all activities producing CO_2; or
- a Pigovian CO_2 tax, such that each tonne of CO_2 emitted from any fossil fuel source is penalized at the same rate. (A Pigovian tax could be represented as so much per tonne of CO_2 emission or as so many dollars per black coal tonne equivalent per year.)

The first method clearly sounds the simplest to implement. It could also be the most expensive. The requirement of a simple quota reduction in CO_2 dioxide, such as the Toronto 20% reduction, will act like a Pigovian tax but with effectively different shadow tax rates, depending on the nature of the product or the area in which the CO_2 reduction is required. The inter-fuel substitution required to meet mandated CO_2 emission reductions will increase costs and hence prices of the products of services supplied.

Similarly, the most decentralized system of abatement control is a differential levy on fossil fuels and other sources of CO_2 in proportions which effectively penalize all emissions of CO_2 (and other greenhouse gases, for that matter) at the same rate. As with tradeable emission quotas, if adjustment is expensive in Tasmania, the electricity authorities might simply choose to pay slightly more for black coal rather than make exceedingly expensive adjustments. In Victoria the levy on brown coal would be higher, forcing that State to turn interstate for black coal or to burn more gas in fuel-efficient ways. The proceeds from a Pigovian levy on CO_2 emissions could be used to reduce income and other taxes generally.

Seidel and Keyes (1983), Nordhaus and Yohe (1983), and Scott et al. (1989) have considered taxes on CO_2 emissions. The first would tax shale oil at 100%, black coal at 52%, oil at 41%, and natural gas at 29%, reflecting the relative CO_2 intensities of the fuels. They found that a coal ban would not be effective if it accelerated the development of shale oil, and it would have other dramatic (and undesirable) effects. A general finding was that if taxes are increasing and sufficiently severe and applied globally, then they can be quite effective at eventually reducing global CO_2 emissions.

3. ENERGY-RELATED CARBON DIOXIDE EMISSIONS IN AUSTRALIA

Oxidation of fossil fuels releases heat, but also produces oxides of carbon (CO_2 and CO) and hydrogen (water). The biomass renewables of wood and bagasse—the spent, dried stalks of sugar cane—as hydrocarbon fuels also produce oxides of carbon when burnt. We shall assume that combustion is complete, so that all carbon is vented in the form of CO_2.

The combustion of renewable biomass results in a positive net flux of CO_2 into the atmosphere if the annual crops are dwindling in mass, and vice versa. It is likely that the net flux from Australian bagasse is about zero, but that continued clearing with no widespread reforestation results in a positive flux from fire-wood. CH_4 produced in the guts of animals also adds to the greenhouse effect, but to the extent that it comes from atmospheric carbon fixed by pasture grasses there is equilibrium in the carbon cycle, although CH_4 is more effective at trapping radiant heat than is CO_2.

The most recent energy-balance figures for 1987/88 enabled us to calculate the amounts of CO_2 being produced from combustion of fossil fuels in Australia (Table 1), given the thermal energy equivalents of the fossil fuels (ABARE 1989)[1] (We found that the

1. Black coal 92 $ktCO_2/PJ$, brown coal 95 $ktCO_2/PJ$, crude oil 69 $ktCO_2/PJ$, petroleum products 73 $ktCO_2/PJ$, natural gas 59 $ktCO_2/PJ$, wood and bagasse 80 $ktCO_2/PJ$.

renewables, wood and bagasse, contributed 13.2 Mt/y of CO_2 emissions in 1987/88, or 5% of the emissions from fossil fuels.)

TABLE 1. Australia—direct and indirect emissions of CO_2 (Mt/y) by end use sector and by fossil fuel—1987/88.

	Black Coal	Brown Coal	Oil Products	Natural Gas	Total Direct	Electr-icity	Grand Total	*Share (%)*
Agriculture & Mining	0.7	0.0	5.8	4.1	10.6	9.1	19.7	*7.5*
Industry	21.8	1.3	11.1	17.2	51.4	47.5	98.9	*37.7*
Transport	0.4	0.0	73.0	0.0	73.4	1.5	74.9	*28.5*
Commercial	0.5	0.2	0.8	1.8	3.3	23.5	26.8	*10.2*
Residential	0.1	0.0	1.3	4.8	6.1	35.9	42.1	*16.0*
Total direct	23.5	1.5	92.0	27.9	144.9	117.4	262.4	*100.0*
Share (%)	*16.2*	*1.0*	*63.5*	*19.3*	*100.0*			
Electricity	69.2	38.3	1.7	8.3	117.4			
Share (%)	*58.9*	*32.6*	*1.5*	*7.1*	*100.0*			
Grand total	92.7	39.8	93.7	36.2	262.4			
Share (%)	*35.3*	*15.0*	*35.7*	*13.8*	*100.0*			

The electricity generation sector is a large source of emissions (44.7%), relying as it does on black and brown coal for 84.2% of its energy inputs; hydro supplies 4.0%. Any success in CO_2 abatement in this sector will be significant in Australia's emissions overall. A second large source of CO_2 emissions is transport, which relies to an overwhelming extent on liquid hydrocarbon fuels. Road transport consumed the equivalent of 761.0 PJ/y of petroleum products, to produce 58.4 Mt/y of CO_2 emissions (22.3%), when refinery losses are pro-rated. The balance of emissions (33.0%) came from other energy conversion and from other end uses. In particular, industrial energy use produced 51.4 Mt/y of CO_2 emissions from the direct use of hydrocarbon fuels and 47.5 Mt/y indirectly from its electricity use (160.3 PJ/y or 47.4 TWh/y, including conversion losses).

There are five ways in which Australia could reduce these emissions:

(1) By capturing or scrubbing the CO_2 from the exhaust and flue gases, but this—although technically feasible for some processes—would be prohibitively expensive for most processes, and certainly more costly than alternative measures.

(2) By substituting lower-carbon fuels for the high-carbon fuels now in use, such as brown and black coal. The use of hydro-power or nuclear-generated electricity would produce no CO_2, but there are other potential environmental problems with these fuels, and at the moment we could not readily substitute these sources for the petroleum produced used in road and air transport. Nonetheless, a move towards natural gas, which currently supplies 18.1% of the country's thermal energy and 13.8% of its energy-related CO_2 emissions, or towards the renewable energy sources would enable Australia to continue using energy at the same or growing levels with lower net emissions of CO_2.

(3) By moving to machines, buildings, and industrial processes which produce the same services with lower energy inputs; that is, to engage in greater levels of energy conservation.

(4) (More drastically): by actually cutting back on the levels of economic activity per person, so that outputs, energy inputs, and CO_2 emissions are all cut. The cost of cutting CO_2 emissions by curtailing end-use activities, such as freeway speeding, is much greater than allowing substitution to occur between, for example, an electric hot-water system and

a solar system.

(5) (Ultimately): by reducing our rate of population growth, which might—other things equal—allow us to increase our per-capita energy use and CO_2 production, while reducing aggregate production of the gas.

Given the advances of technological knowledge, there is always a lag in the implementation and availability of energy-saving techniques, and given the durability of the stock of energy-using equipment, there is a further gap between average energy efficiency and the higher levels of energy efficiency of new equipment. Despite the availability of new, economically viable techniques for energy substitution and conservation, some observers have claimed that consumers—whether households or companies—are not taking advantage of these techniques by investing in new equipment to save both money and energy, and hence to reduce CO_2 emissions.

The economist is wary of claims that there exist unappropriated rents. The wariness is higher in cases of firms in competitive markets apparently ignoring such opportunities, and lower when knowledge of energy-saving possibilities is costly to acquire and when potential savings are a small proportion of total costs. Whether cost-effective or not for individual households or firms, the problem remains for society to induce a change in individuals' and organizations' behavior: to use "cleaner" fuels, to invest in more energy-efficient equipment, to cut back on end-use activities, or some combination of all three.

4. ELECTRICITY

CO_2 intensity per unit of electricity generated varies by State, from the hydro of Tasmania (very low) to the brown coal of Victoria (over 1 kt/GWh). Tradeable permits or Pigovian taxes, while necessary for efficient emission reductions, will not obviate the need for more investment, in State grid interconnections (Marks, 1986), and in new generation and transportation facilities.

Using a comprehensive electricity generating cost model, the Report examines New South Wales (NSW) for CO_2 reductions closely, and extrapolates to the other States to derive a composite outcome of costs and reductions for Australia as a whole.

4.1 Reducing CO_2 *emissions*

From the discussion in Section 3 above, the key options for cutting CO_2 emissions from electricity are: (2) the use of generating technology with higher thermal efficiencies and/or less CO_2-intensive fuels, and encouraging customers to install energy-efficient co-generation facilities; and (3) influencing industries and households to consume less energy. This can be through better information on the benefits of using more efficient/cost-effective devices and/or through increasing prices to discourage overall demand.

Substantial reductions in CO_2 emissions can be made using proven technologies. Changing to less CO_2-intensive fuels in the Australian context means switching from brown to black coal, and from black coal to natural gas. Renewable energy sources such as hydro, wind, photovoltaics and wave energy are environmentally attractive, but their ability to make a significant contribution to electricity generation over the next fifteen years is limited. In particular, environmental concerns limit options for additional hydro dams, and high capital costs of the other technologies so far make them quite uneconomic, and the long lead times in commercializing new energy sources rules out the fuel cell, photovoltaic cell, and magnetohydrodynamic combined-cycle technologies, substantial gas turbine improvements, ultra-clean coal, and nuclear power.

The key questions are: what will these technologies cost? and how much CO_2 can be saved? The cheapest way of reducing CO_2 emissions is to build black coal plants in place of new brown coal plants. The Report examines different generating technologies, for cost of tonne CO_2 emissions saved compared with the base case of brown coal. Black coal dominates brown: it is both cleaner and cheaper. For others, the tradeoff implies a cost per tonne of CO_2 saved; in increasing order of expense: co-generation, CH_4 recovery, hydro, advanced gas turbine, wind, combined gas cycle, and photovoltaics.

So the cheapest way for those States that already generate much of their energy from efficient black coal-fired plant to significantly reduce CO_2 emissions is to switch to burning natural gas in a turbine or combined cycle plant. Changing over from an efficient black coal-fired plant to, say, a combined cycle facility would reduce unit CO_2 emissions by 48% (from 940 to 490t/GWh), but at a cost of A$45-75 per tonne of CO_2 saved. For a gas price of A$4/GJ, this is nearly twice that of changing over from brown coal to a gas fired-combined cycle plant (of A$25–47 per tonne in Victoria). To shift from brown coal to natural gas (or black coal) is cheaper than from natural gas to a less CO_2-intensive mode of generation. Hence, it is relatively less expensive for Victoria to adopt a given CO_2-saving technology than for other States.

4.2 The scenarios

The State utilities predict growth in consumption of about 2.8% p.a. for the study period, which would result in CO_2 emissions rising 57% above 1988 levels on average to 2005. The Base Case predicts a growth of Gross Domestic Product (GDP) of 3.44% p.a., which, from extrapolation of past experience, would result in a growth of at least 5% p.a. in electricity consumption. Since the individual States will exhibit base-case growth in CO_2 emissions from 34% in Victoria to 187% in the Northern Territory, a uniform 20% reduction from 1988 levels will also vary in cost across States.

The Report considered three scenarios beyond the base case: a "moderate technology fix", with small-scale hydro, gas-fired turbines, co-generation, costless conservation, privately owned CH_4 recovery facilities, and improved plant maintenance and management; a "severe technology fix", as above with accelerated retirement of old plant, combined-cycle natural gas plant, and private wind generators; and "severest technology fix and pricing", as above with further retirements, conservation, and steep price increases.

For NSW, the third scenario—a combination of new technology, accelerated retirements, and demand-reducing price increases—was found to be necessary. The analysis suggests that a 40% increase in electricity prices above the base case is required by 2005, together with the substitutions described above on the supply side. The analysis reveals that 30% will be higher costs to cover the alterations on the supply side and 10% from higher electricity taxes. As a rule of thumb for NSW, a 1% reduction in CO_2 emissions will lead to an increase in price of 0.4–0.8%.

The Report builds on a study by the Victoria State utility (SECV, 1989) to conclude that, as one would expect, the cost of a 20% reduction in CO_2 emissions is lower (a 25% rise in prices) for the high-emission utility, through aggressive demand management and the installation of energy-efficient equipment. Of course, the corollary is that the national interest is best served by a greater percentage cut in Victorian emissions than elsewhere, especially hydro-powered Tasmania. These trade-offs between Australian electricity utilities are similar, if easier, to the trade-offs necessary between nations, if the adjustment to abatement world-wide is not to be excessively costly.

4.3 Meeting the Toronto target

We estimate that meeting the Toronto target will lead to 25% and 40% price increases in Victoria and NSW, respectively (over the base case). The lower rate in Victoria reflects the higher starting point for the SECV: because brown coal-based generation is more CO_2-intensive than other methods, it is easy to achieve significant reductions through other conventional technologies.

Given that Victoria and NSW produce two-thirds of all CO_2 generated in Australia, we conservatively estimate that meeting the Toronto target will increase real national electricity prices by around 40% (on a weighted basis) between 1988 and 2005. This corresponds to an average of 2.0% p.a. increase in electricity costs over the period to 2005 over what would otherwise have been the case. Of that 2.0%, about 1.5% represents costs of the necessary changes in the system and about 0.5% represents a levy to further suppress demand.

There are three assumptions underlying this estimate. First, a national long-run price elasticity of demand for electricity of –0.5. Second, the base case projection that demand for electricity is likely to increase at less than the underlying growth in GDP. Third, gas price rises will be moderate (conforming with Australian Gas Association projections)—that is, increasing by about 19% over the period. This is conservative, since the world demand for gas will increase with the onset of greenhouse warming.

5. ROAD TRANSPORT

As seen from Table 1, the transport sector generated 74.9 Mt/y of CO_2 emissions in 1987/88, 28.5% of total emissions from fossil fuels. ABARE (1989) figures show that road transport fuel consumption was 79.3%, and air transport fuel consumption was 11.2%, of total transport fuel consumption of 959.9 PJ/y in 1987/88.

5.1 Two scenarios for road transport fuel

Base-case projections Using a commercial model for motor gasoline consumption, with base-case assumptions about the macroeconomic environment (see Table 2), we have derived base-case projections for road fuel use through 2005. In the Base Case the consumption of gasoline grows at an average annual rate of 1.78%, while consumption of diesel and LPG grows at 3.0% p.a., implying an income elasticity of 1.0. This implies an average growth rate of 2.12% p.a. for total road fuel. The base-case assumption of a 0.7% p.a. improvement in fuel efficiency would result in the total fleet average fuel efficiency improving from about 13.6 L/100 km in 1988 to 12.1 L/100 km in 2005. We see in Table 3 that from 57.3 Mt/y of CO_2 emissions in 1988, the base case projects 82.3 Mt/y of CO_2 emissions in 2005, an increase of 43.6% above 1988. But the Toronto target is a 20% reduction by this date.

High-efficiency scenario In the high-efficiency scenario we examine how effective the improvements in fuel efficiency outlined below would be in reducing fuel consumption and hence in reducing CO_2 emissions. We chose these particular improvements because they are the most optimistic projections of efficiency and costs with existing technology available.

Goldemberg et al. (1988, p.460) discuss potential fuel efficiency improvements possible today, at a total cost of over 25% of the unimproved cost of new passenger vehicles. We assume that the following improvements will progressively be introduced to new vehicles: all new vehicles diesel-powered, tire rolling resistance reduced, reduction in

TABLE 2. Base-case projections of fuel use in transport—major assumptions—annual average percentage growth.

	Assumed 1989–2005	Actual 1980–1988
Population	1.4	1.4
Real Gross Net Expenditure	3.0	3.3
Real Gross Domestic Product	3.0	3.7
Consumer Price Index	5.0	8.3
Real new passenger vehicle prices	0.0	1.7
Real motor gasoline price	0.0	0.0
Passenger vehicle fleet average fuel efficiency improvement	0.7	0.7

aerodynamic drag to (0.3), from pre-chamber to open chamber diesel, from manual transmission to continuous variable transmission (CVT) 5:1, weight reduction, extended range of CVT (10:1), engine-off during idle and coast (for details, see von Hippel and Levi, 1983). These would increase the average fuel efficiency of the new vehicles from 11.0 L/100 km in 1988 to an extreme of 4.6 L/100 km in 2005, an extraordinary reduction, if it occurred. We assume that the fuel-efficiency improvements are progressively introduced in new vehicles over the sixteen-year period 1989–2005; so the cost of new vehicles progressively rises over this period to a maximum of 25% above the base case. The effects of these improvements on energy use and CO_2 emissions to 2005 are shown in Table 3.

In this scenario we assume that real new passenger vehicle prices rise at 1.3% p.a. instead of zero as in the base case, as a result of the embodiment of fuel-efficiency measures which result in an average fuel efficiency improvement for the passenger vehicle fleet of 1.7% p.a. instead of 0.7% p.a. in the base case. The commercial model predicts an increase of gasoline consumption in this scenario of 0.73% p.a. In addition, we assume that the consumption of diesel and LPG grows at 1.3% p.a., which implies an average growth rate of 0.88% p.a. for total road fuel. We see in Table 3 that this scenario projects CO_2 emissions of 66.6 Mt/y in 2005, an increase of 16.2% over 1988 emissions. In this scenario, the assumption of 1.7% p.a. improvement would result in a figure of 10.2 L/100 km in 2005 for the total vehicle fleet.

Price effects on transport fuel use To reduce fuel use and hence CO_2 emissions further the Report considered increasing the price of fuel. Using a conservative OECD estimate of long-run own-price elasticity of demand for transport energy of between 0.3 and 0.6 (IEA, 1987, p.46)[2], we see that to reduce demand by 10% would require prices to rise by between 16.7% and 33.3%.

The Toronto target for CO_2 emissions of 20% below the 1988 level is 45.8 Mt. This would require a reduction of 44.4% from the Base Case, or 31.2% from the High Efficiency Scenario. These correspond to equal annual turnarounds of 3.45% p.a. and 2.20% p.a. in emissions over the seventeen-year period. To attain these reductions from higher prices, given a price elasticity of demand of between 0.3 and 0.6, would entail price rises of between 5.75% p.a. and 11.49% p.a for the Base Case, or between 3.67% p.a. and 7.34% p.a. for the High Efficiency Scenario. These results are summarized in Table 3.

2. The commercial model assumed a lower, short-run elasticity of 0.2. The price rises necessary to attain Toronto are, of course, highly sensitive to the assumed elasticity.

TABLE 3. Scenarios for road transport CO_2 emission abatement.

	Fuel Energy (PJ/y)	CO_2 Emissions (Mt/y)	Emissions ÷ 1988 (%)
1988 Actual	783	57.3	Base
2005 Base Case	1,124	82.3	+43.6
2005 High-efficiency scenario	910	66.6	+16.2
2005 Base Case with fuel prices rising at 5.7%–11.5% p.a.	626	45.8	−20
2005 High-efficiency scenario with fuel prices rising at 3.7%–7.3% p.a.	626	45.8	−20

6. MACRO-ECONOMIC EFFECTS

ORANI (Dixon et al. 1982) is a macro-economic model of the Australian economy based on input–output coefficients of 112 industries. It was used to examine possible macro-economic implications for Australia of attempts to reduce CO_2 emissions, both unilaterally and in coöperation with the rest of the world. The model was used to examine the macro-economic effects of:

a. increased costs, including capital replacement costs, in the electricity industry brought about by the need to substitute lower CO_2-emitting fuels for fuels with high CO_2 emission;

b. the imposition of taxes on electricity generation designed to reduce electricity usage;

c. increased costs, including capital replacement costs, in the road transport industry brought about by the need to reduce CO_2 emissions by using more expensive fuels or more fuel-efficient vehicles;

d. the imposition of taxes on road transport designed to reduce road transport usage;

e. the effects on the Australian economy of a fall in the world price of coal.

A base-case macro-economic projection consistent with the base cases for the electricity and road-transport sectors, above, was developed in terms of a range of external and domestic macro variables for the period 1988–2005. The projection focused on the average annual growth of real GDP, the real hourly wage rate before tax, and real private consumption, as shown in Table 4. The unit sensitivities of these variables to 1% p.a. shocks in each of the five variables mentioned above were calculated, Table 4. This means that, for example, with a 1% p.a. annual increase in the input requirements per unit of electricity production, real wages would grow at 0.2297% p.a. instead of 0.29% p.a.

TABLE 4. Unit Sensitivities (percentage points p.a.) to Shocks

	Base Case (%p.a.)	Shock				
		Electricity		Road Transport		Coal Prices
		Increased Inputs	Tax	Increased Inputs	Tax	Fall
Real GDP	*3.44*	–0.0393	–0.0015	–0.0507	–0.0087	–0.0159
Real wages	*0.29*	–0.0903	–0.0809	–0.1179	–0.1023	–0.0662
Private consumption	*2.29*	–0.0614	0.0106	–0.0500	0.0146	–0.0277

Since the ORANI model is linear in percentage growth rates, the unit sensitivities can be scaled to obtain the effects of shocks other than 1% p.a., and may also be added to obtain the effects of more than one shock simultaneously. The unit sensitivities are not themselves especially sensitive to the base forecasts. Using the unit sensitivities of real GDP growth, we can calculate the cost of growth forgone corresponding to increased inputs for electricity of 1.5% p.a., a tax on electricity of 0.5% p.a., increased inputs for road transport of 0.092% p.a., and a tax on fuel of 3.7% p.a.

6.1 Results of the ORANI simulations

The effects on the base case growth of GDP of a 1% p.a. increase in the growth of real electricity costs depend on whether the costs are rising because of an increase in the input requirements per unit of electricity generated or because of an increase in taxation. Increased inputs will have a more serious effect on the growth rate of GDP than will taxation, because the tax revenues are not dead-weight loss, but rather represent a transfer of resources in the economy, as shown in Table 4.

ORANI provides linear approximations to the dead-weight losses as a function of changes in the rate of change of costs or prices. For a linear demand function, the dead-weight loss associated with a tax is a quadratic function of the change in price. For small changes in the rate of change of price, these linear approximations are probably close to the true growth effects, but for large changes the approximations may well underestimate the true growth effects and hence of the true dead-weight losses.

6.2 Forgone economic growth

In order to put a dollar value on the dead-weight losses, in each case, for two discount rates (5% p.a. and 10% p.a.), we calculate the difference between the present value of seventeen years of growth of GDP at 3.44% p.a. from 1987/88 to 2004/5 and the present value of these seventeen years of growth of GDP at the slightly lower annual rate after the effects of the cost increases on GDP growth have been taken into account.

From Table 4, a 1% p.a. annual increase in costs to road transport via a tax increase (resulting in a surcharge of 18.4% after the seventeen years from 1988 to 2005) would reduce the base forecast of (GDP) growth by 2.5%, from 3.4400% p.a. to 3.4313% p.a., a cost in the year 2005 of 0.254% of the 1988 GDP; in the base case, 2005 GDP would be 77.71% greater in real terms than that of 1988. The effects in the intervening years would be a lower percentage of each year's GDP.

From Table 3, to attain the Toronto target with the Goldemberg Improvements to fuel efficiency would require fuel prices to rise at between 3.7% and 7.3% p.a., and the improvements to fuel efficiency would, if progressively introduced over the seventeen years, lead to an increase in new car prices of 1.32% p.a. above the base case, so that in 2005 the cost of a new car would be 25% higher than the case without the improvements.

Assuming that 7% of the Australian fleet is newly purchased each year, the effect of the rise in new car prices would be to increase costs overall by 0.09% p.a.

Table 5 summarizes the effects on the base case GDP growth (of 3.44% p.a.) of the various scenarios and presents the present values of the forgone growth in GDP for the two discount rates. Row 7 presents the cost of joint reductions in emissions from electricity generation and from road transport. The present value at 5% p.a. is A$34,456 million (or A$20,244 million, at 10% p.a.). Row 8 presents the effect, according to ORANI, of a 1% p.a. fall in world coal prices on the Australian economy. The main effect is a fall in average annual growth in GDP of 0.0159 percentage points p.a. The difference in the present value of the economic growth forgone over the seventeen-year period is calculated as above at A$5,686 million at 5% p.a., or A$3,339 million at 10% p.a.

TABLE 5. Economic costs of abatement scenarios.

	Change in Annual GDP Growth (% p.a.)	Economic Cost	
		5% p.a. Discount Rate (1989 A$ million)	10% p.a. Discount Rate (1989 A$ million)
1. Electricity costs rising at 1.5% p.a. (increased inputs)	0.05895	21,031	12,351
2. Electricity costs rising at 0.5% p.a. (increased taxes)	0.00075	268	158
3. Total electricity costs (1+2)	0.0597	21,299	12,509
4. Road transport costs rising at 0.092% p.a. (Goldemberg fuel efficiency improvements)	0.0047	1,667	979
5. Road transport costs rising at 3.7% p.a. (increased taxes)	0.0322	11,490	6,756
6. Road transport, high efficiency (4+5)	0.0369	13,157	7,735
7. Total electricity and road transport, High efficiency (3+6)	0.0966	34,456	20,244
8. Fall in world coal prices of 1% p.a.	0.0159	5,686	3,339

It would be incorrect to infer that, because we have given point estimates of prices, quantities, and costs, we are confident in our figures. We have tried to be conservative in our estimates, but the results are sensitive to price elasticities of demand, to growth rates, to discount rates, and to the methodology underlying the ORANI model. Nonetheless, we feel confident that the estimates of the present values of the dead-weight losses associated with various scenarios for reducing the CO_2 emission in Australia to the Toronto target of a 20% reduction from 1988 levels are at the low end of projected efficiency costs, and provide a datum for future policy analysis of the cost-effectiveness of attaining the Toronto targets.

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