11 COSTING CLIMATE CHANGE AND ITS AVOIDANCE

Key points

Type 1 (modelled median outcomes) plus Type 2 (estimates of other median outcomes) costs of climate change in the 21st century are much higher than earlier studies suggested. The Platinum Age emissions grow much faster than earlier studies contemplated.

The modelling of the 550 mitigation case shows mitigation cutting the growth rate over the next half century, and lifting it somewhat in the last decades of the century.

GNP is higher with 550 mitigation than without by the end of the century. The loss of present value of median climate change GNP through the century will be outweighed by Type 3 (insurance value) and Type 4 (non-market values) benefits this century, and much larger benefits of all kinds in later years.

Mitigation for 450 costs almost a percentage point more than 550 mitigation of the present value of GNP through the 21st century. The stronger mitigation is justified by Type 3 (insurance value) and Type 4 (non-market values) benefits in the 21st century and much larger benefits beyond. In this context, the costs of action are less than the costs of inaction.

Does participation in global mitigation, with Australia playing a proportionate part, and with all the costs of that part, make sense for Australia? If so, what extent of mitigation would give the greatest benefits over costs of mitigation for Australians?

The costs of mitigation come early, and the benefits of mitigation through avoided costs of climate change come later. The costs of mitigation are defined clearly enough to be assessed through standard general equilibrium modelling. The benefits of mitigation come in four types, only one of which is measurable with standard modelling techniques. This chapter applies the decision-making framework of Chapter 1 to the fundamental question before the Review. The analysis is informed by the modelling undertaken jointly with the Australian Treasury and independently by the Review.

11.1 The three global scenarios

This chapter analyses the three scenarios introduced in Chapter 4—the no-mitigation scenario, in which the world does not attempt to reduce greenhouse gas emissions; and the 550 and 450 scenarios, which represent cooperative global efforts to reduce emissions to varying degrees. To answer the question of whether Australia should support, and play its full part in, a global mitigation effort, the Review compared the costs and benefits of the no-mitigation and the 550 scenarios. To answer the question of how much mitigation Australia should support the Review compared the 450 and 550 scenarios. What is compared, through a mix of modelling and analysis, is the cost to Australia of participating in a global agreement to mitigate climate change, and the costs of climate change under the three scenarios.

In 2005, the atmospheric concentration of greenhouse gases was about 455 parts per million (ppm) of carbon dioxide equivalent (CO_2-e). In the no-mitigation world, under the view of business-as-usual emissions presented in Chapter 3, this would reach 550 ppm by 2030, 750 by 2050, 1000 by 2070, and 1600 by 2100.

The concentration of carbon dioxide (the main greenhouse gas) in this scenario would reach 1000 ppm at 2100, compared to a band of natural variability of carbon dioxide over many millennia of between 180 and 280 ppm, and 280 ppm in the early years of modern economic growth in 1840.

In the 550 scenario, concentrations of greenhouse gases stop rising by around 2060, and after slight overshooting, stabilise around 550 ppm CO_2-e, one-third of the level reached in the no-mitigation scenario, by the end of the century. In the more stringent 450 scenario, given the current concentration, significant overshooting above 450 ppm CO_2-e is inevitable. Concentrations peak at 530 ppm CO_2-e around 2050, and decline towards stabilisation at 450 ppm CO_2-e early in the 22nd century.

Atmospheric concentrations of greenhouse gases are important primarily because of their impact on global temperature. Table 11.1 shows the expected increases in global temperature associated with each of the three scenarios, as well as the temperature consistent with the highest climate sensitivity in the 'likely' range defined by the IPCC—that is, two-thirds probability of remaining within the limits (IPCC 2007). In the absence of mitigation, in the median case, the world is heading for a 2.3°C increase over 1990 levels by 2050, and 5.1°C by 2100. Temperatures would continue to rise by as much as 8.3°C by the end of the next century, or higher if the climate sensitivity were above its central estimate.

The 550 and 450 scenarios will limit median expectations of end-of-century temperature increases to 2°C and 1.6°C, respectively, above 1990 levels under the central estimate for climate sensitivity, and stabilise global temperatures at just above these levels. Even so, an end-of-century increase of 2.7°C and 2.1°C, respectively, above 1990 levels is still within the likely range of the 550 and 450 scenarios (Table 11.1).

Table 11.1 Temperature increases above 1990 levels under the no-mitigation, 550 and 450 scenarios

	2050		2100		2200	
	Best estimate	Upper end of likely range	Best estimate	Upper end of likely range	Best estimate	Upper end of likely range
No mitigation	2.3°C	2.9°C	5.1°C	6.6°C	8.3°C	11.5°C
550	1.7°C	2.2°C	2.0°C	2.7°C	2.2°C	3.1°C
450	1.6°C	2.1°C	1.5°C	2.1°C	1.1°C	1.7°C

Note: The 'best estimate' and 'upper end of likely range' temperature outcomes were calculated using climate sensitivities of 3°C and 4.5°C respectively. There is a two-thirds probability of outcomes falling within the likely range. Temperatures are derived from the MAGICC climate model (Wigley 2003). Temperature outcomes beyond 2100 are calculated under the simplifying assumption that emissions levels reached in each scenario in the year 2100 continue unchanged. They do not reflect an extension of the economic analysis underlying these scenarios out to 2100, and are illustrative only. It is unlikely that emissions in the reference case will stabilise abruptly in 2101 with no policies in place, and hence the temperatures shown underestimate the likely warming outcomes if continued growth in emissions is assumed. 1990 temperatures are about 0.5°C above pre-industrial levels.

11.2 Comparing the costs of climate change and mitigation

To understand the potential economic implications of climate change for Australia, appropriate scientific and economic frameworks must be combined to estimate impacts. This is not a trivial task. There is uncertainty in many aspects of climate change science at the climate system, biophysical and impact assessment levels. These compounding sources of uncertainty mean that quantifying the economic impacts of both climate change and its mitigation is a difficult, and at times speculative, task. The Stern Review (2007: 161) cautioned that 'modelling the overall impact of climate change is a formidable challenge, demanding caution in interpreting results'. Moreover, modelling alone will not provide an answer to the two questions posed at the beginning of this chapter. As explained in Chapter 1, many of the costs of climate change cannot be modelled.

The framework set out in Chapter 1 distinguished between four types of costs of climate change. The first type of cost (Type 1) has been measured through a computable general equilibrium model, based on measured market impacts of climate change in the median or 'average' cases suggested by the science. That is the easiest part of the problem, but still involves the most complex long-term modelling of the Australian economy ever undertaken. The requirement to model changes in the structure of the Australian economy in a general equilibrium framework to the end of the 21st century takes the models to the limits of their capacities. For details on the combination of models used, see Box 11.1.

Box 11.1 The Review's modelling

The Review's innovation was to model the cost of imposing mitigation policy alongside the benefits of the climate change avoided. This was done as follows:

- **Step 1:** A reference case of no climate change and no climate change policy was developed jointly by the Review and the Australian Treasury.
- **Step 2:** A 'no mitigation' policy scenario was developed by the Review that entailed shocking the reference case to simulate a world of unmitigated climate change.
- **Step 3:** The effect of mitigation policy was modelled by (1) imposing a carbon constraint on the model, and (2) imposing 'positive' climate shocks to simulate a lesser degree of climate change as a result of successful global mitigation policy (that is, 550 ppm or 450 ppm).

This was a highly complex and technically pathbreaking process, which required the Review to draw on a wide range of expertise and models within individual sectors. The modelling of the expected impacts of climate change by the Review included individual areas of impact, including agriculture, human health and several aspects of infrastructure.

There is currently no single model that can capture the global, national, regional and sectoral detail that was necessary for the Review's approach. As a result, the Review drew on a number of economic models to determine the costs of climate change and the costs and benefits of climate change mitigation for the Australian economy. The key models used were the Monash Multi Regional Forecasting (MMRF) model, the Global Trade and Environment Model (GTEM) and the Global Integrated Assessment Model (GIAM). The focus of the modelling of both mitigation and climate damage costs was on Australia. However, GTEM and GIAM—which extends GTEM to model the interaction between the climate system and the economy—were used to model global mitigation and climate change damages. The outcomes of this modelling (in particular, the global carbon price, and Australia's emissions entitlement and trade impacts) were fed into the MMRF model. MMRF was augmented by a series of scientific and economic models, including for the electricity, transport, and land-use change and forestry sectors. This allowed the determination of the costs of unmitigated climate change and the net costs of mitigation to Australia. GTEM was also used to derive mitigation costs for Australia, but, unlike MMRF, without calculation of avoided climate change.

In interpreting the results of the modelling, it is important to bear in mind that only one of the four types of costs of unmitigated climate change, and therefore only one of the four types of benefits of avoided climate change from mitigation, could be captured in the model.

Further details of the modelling and the climate change impact work undertaken by the Review are available in a technical appendix at <www.garnautreview.org.au>. The Review looks forward to further empirical work and refinement by others of its modelling of climate change.

The second type of cost (Type 2) involves market impacts in the median cases, for which effects cannot be measured with sufficient precision and confidence to feed into a computable general equilibrium model. By their nature, these costs and benefits are not amenable to precise quantification. The Review formed judgments about likely magnitudes, relative to the size of the impacts that were the focus of the formal modelling. These assessments were applied in a transparent way in adjustments to some of the model results, to remove the bias that would otherwise be associated with the exclusion of obviously important market impacts for which data were not available at the time of the modelling work. This is not as good as modelling these costs within the general equilibrium framework would have been if the data had been available, but it is clearly better than leaving them out altogether.

The third type of cost (Type 3) is that associated with the chance that the impacts through market processes turn out to be substantially more severe than suggested in the median cases. Type 3 costs derive their importance from the normal human aversion to risk in relation to severe outcomes, and from the possibility that the bad end of the probability distribution includes outcomes that are extremely damaging and in some cases catastrophic. Since the modelling undertaken was not of a probabilistic nature, these 'worst case' impacts could not be quantified.

The fourth type of cost (Type 4) involves services that Australians value, but which do not derive their value from market processes. Examples include deterioration of environmental amenity; loss of species and, more generally, of biodiversity; and health and international development impacts that do not necessarily have their effects through the imposition of monetary costs on the Australian community. By definition, these costs cannot be included in the modelling.

In contrast to three of the four types of climate change induced costs, all mitigation costs have a market impact and so can be measured.

The other difference between mitigation costs and climate change costs is their profile over time. The Review's modelling of the effects of climate change ends in 2100. The long time frames and large structural shifts involved in climate change analysis present considerable challenges for modelling the way the economy is likely to respond. As in most economic models, the assumed behavioural responses in models used by the Review are determined by parameters and data that have been derived from recent history. Into the second half of this century and beyond, the assumptions that must be made about economic parameters and relationships become highly speculative. And yet all of the detailed assessments of the economics of climate change indicate that the main costs of climate change, and therefore the main benefits of mitigation, accrue in the 22nd and 23rd centuries and beyond (Stern 2006; Nordhaus 2008; Cline 2004). Whereas the costs of *mitigation* can be expected to stabilise this century, the costs of *climate change* can be expected to accelerate over this century and into the next. Consideration of the long-term costs and benefits must be a feature of any evaluation of the net benefits of climate change mitigation policy.

Because of the importance of the non-quantified costs of climate change—whether they are Type 3 or Type 4 costs this century, or any of the types of costs beyond this century—a comparison of the modelled costs of mitigation and no mitigation, or even of differing degrees of mitigation, can only contribute to any comparison of two scenarios. What can be modelled are the gross costs of mitigation (purely the costs of mitigation without any of the benefits of avoided climate change) and the net costs of mitigation (the gross costs of mitigation minus the modelled Type 1 impacts and the estimated Type 2 impacts). These costs of mitigation (modelled at most out to 2100) need to be compared with judgments concerning the non-quantified Type 3 and Type 4 benefits from mitigation this century, and with the likely benefits (of all types) from climate change avoided in the next century and subsequent centuries.

11.3 Modelling mitigation

The modelling of the two mitigation scenarios is based on costs associated with Australia's adherence to an emissions allocation, derived from an international agreement commencing in 2013, to limit the concentration of greenhouse gases to 450 and 550 ppm CO_2-e respectively. As shown in Chapter 9, under the 550 scenario Australia's emissions entitlement allocation in 2050 relative to 2000 emissions in absolute terms falls by 80 per cent, and in the 450 scenario by 90 per cent. Australia's emissions can exceed that allocation if we buy permits from other countries at the global carbon price, which prevails across all sectors within Australia, and across all countries around the world. The global carbon price increases over time, along a path which ensures that emissions fall sufficiently for either of the two concentration targets to be achieved.[1] As a small emitter in global terms, Australia's emissions do not affect the global carbon price, which is taken as a given in the domestic modelling. All revenues raised from sales of carbon permits are distributed back to households. No payments are made to the trade-exposed sector, as all industries around the world face the same emissions penalty. No compensation payments are made to industry.

A critical determinant of the costs of mitigation is the assumptions made about technologies that are or will become available to reduce emissions. Technological development of any type is difficult to predict. When powerful incentives to innovation are introduced to a market environment, however, human ingenuity usually surprises on the upside. How will this ingenuity manifest itself in the face of high emissions prices and increased public support on a global scale for research, development and commercialisation of low-emissions technologies?

We do not know, but there are good reasons to believe that, if we get the policy settings right over the next few years, the technological realities later in the century will be greatly superior to those which, for good reason, are embodied in the standard technology variants of the models used by the Review.[2]

As one alternative to the *standard technology* assumptions, the Review modelled an *enhanced technology* future, embodying various assumptions of more rapid technological progress, none of which seems unlikely.[3]

As another possibility for the future, the Review examined the implications of the commercialisation of a *backstop technology* encouraged by high carbon prices, that, at a cost of $250 per tonne of CO_2-e, takes greenhouse gases from the atmosphere for recycling or permanent sequestration. In the Review's modelling of the backstop, deployment starts between 2050 and 2075.

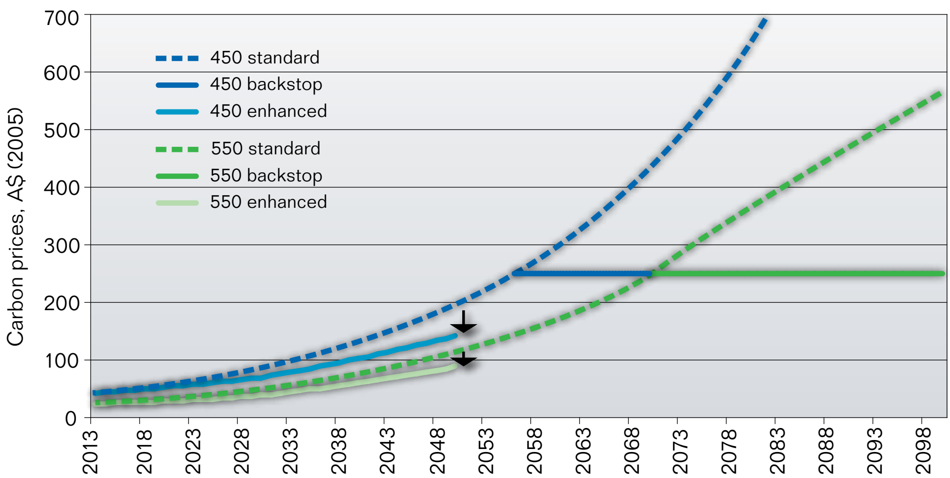
The backstop technology has been introduced into the modelling in a stylised manner. No single technology has been modelled. Rather, the backstop technology is assumed to be available for all industries. In practice, the most likely backstop technology will not be industry specific, but will, at a substantial cost, extract carbon dioxide from the air for recycling or sequestration.

While the backstop and enhanced technologies are possibly complementary, they are assumed to be alternatives in the modelling.

Which of these three visions of the technological future, or which combination of them, or which alternative to all of them, defines the opportunities that evolve through market processes over the years ahead will be revealed in due course. Technological developments in response to a rising carbon price will have a large effect on the acceptability to the global community of 450 and 400 ppm CO_2-e mitigation strategies in future years.

Figure 11.1 shows the 450 and 550 global carbon prices in 2005 Australian dollars under different assumptions about technology.

Figure 11.1 Australia's carbon prices under different mitigation scenarios and technological assumptions



Note: The rising carbon price paths are derived in GTEM and implemented in MMRF, except for the prices derived under the enhanced technology assumptions, which are implemented only in GTEM and reported up to 2050. The 450 and 550 price paths move on to the horizontal backstop path when they reach about $250/t CO_2-e. The two arrows show the extent to which the enhanced technology assumptions reduce the carbon price relative to the standard technology assumptions.

Taking into account the deadweight costs, negative and positive, of various policies that are used to achieve reductions in emissions is just as difficult as imagining the technological future. Nordhaus's pioneering work (1994) emphasised the reductions in deadweight costs that could come from replacing distorting forms of taxation, such as income tax, by a carbon tax. Mitigation through a carbon tax—no exemptions, no shielding of trade-exposed industries—had a positive economic benefit, because the carbon tax was less economically distorting than the taxes that it replaced. A similar result could be obtained by replacing distorting Australian taxes with revenue from the competitive sale of permits from an emissions trading scheme. However, a distorted Australian emissions trading scheme that diverts management effort from commercial activities into applying pressure for political preferment could have large negative deadweight costs.

The modelling has assumed no net transactions and other deadweight costs of the mitigation regime. History will reveal whether this was an optimistic or pessimistic assumption.

The costs of mitigation depend on who bears them. Generally, an increment of money is judged to be more valuable to the poor than the rich. It follows that the costs of mitigation are higher, and the optimal amount of mitigation effort lower, the more the costs are carried by the poor. More mitigation is justified if compensation for low-income Australian households is a major feature of the policy framework. (Chapter 16 explores the distributional impacts of mitigation.) Similarly, more global mitigation can be justified if low-income countries carry a low proportion of the costs. Australia has a strong interest in the burden of mitigation being borne equitably across countries and therefore disproportionately by developed economies, as Australia's terms of trade would be damaged most by any setback to income growth in developing countries.

11.4 The decision to mitigate

Is global mitigation in Australia's interests? To test the case for action, the Review compared the no-mitigation and 550 scenarios, and compared the costs of mitigation of climate change with the benefits of avoiding climate change (the difference between the costs of climate change with and without mitigation). The costs of mitigation and the benefits of avoiding some of the costs of climate change are those associated with implementation of a 550 stabilisation strategy.

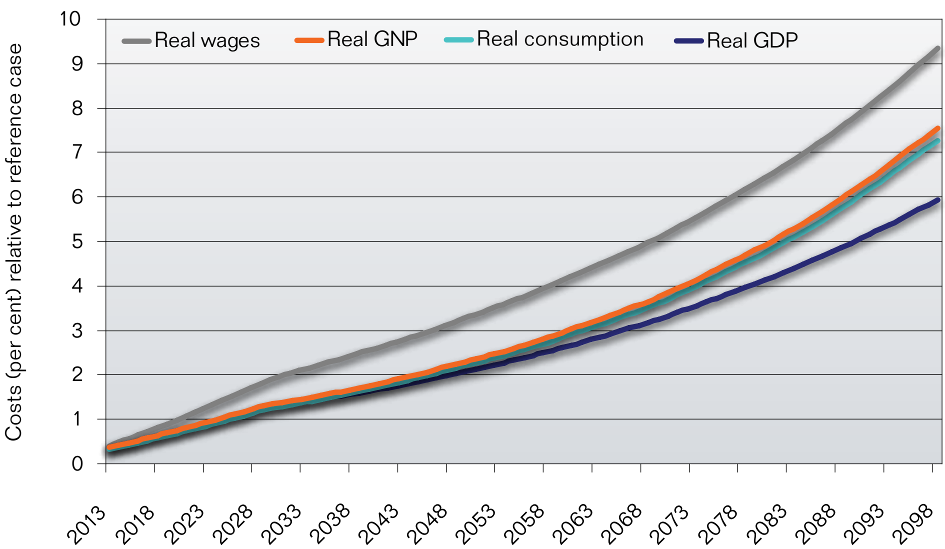
The case for mitigation rests on the large temperature increases that would be a likely outcome—not a remote possibility—of the rapid emissions growth that can be expected in the absence of mitigation. The updated, realistic projections of emissions growth developed by the Review, combined with mainstream scientific estimates of climate sensitivity, result in a best estimate of the no-mitigation scenario giving rise to a 5°C temperature increase over the course of this century. This would at best impose severe costs on the world and on Australia.

11.4.1 The cost of unmitigated climate change

Type 1 costs: modelled expected market impacts of climate change

The Review's economic modelling focused on five key areas of impact (primary production, human health, infrastructure, tropical cyclones and international trade). In each of these areas, climate change shocks were imposed reflecting the best estimates and judgments available on the likely market costs of climate change.[4] (See Table 11.2.) The modelled market impacts of unmitigated climate change relative to a world without climate change (the reference case of chapters 3 and 7) are shown in Figure 11.2.

Figure 11.2 The modelled expected market costs (median case) for Australia of unmitigated climate change, 2013 to 2100 (Type 1 costs only)



Note: All variables in this figure and throughout this chapter are in 2005 prices.

The modelled costs of climate change rise over time. Household consumption and GNP on the one hand, and GDP on the other, diverge through time due to the projected fall in Australia's terms of trade relative to the reference case.[5] If this occurs, a greater volume of exports is required to pay for the same volume of imports. Since consumption tracks GNP closely, most of the results are reported in terms of GNP.

Changes in labour demand are captured in large changes to wages, rather than unemployment, as the wage rate moves to eliminate any short-run employment effects from climate change. Unmitigated climate change causes real wages to be around 12 per cent lower than they would otherwise have been. The fall in real wages increases significantly in the second half of the century in response to reduced demand for labour as a result of climate change.

Table 11.2 Assessing the market impacts of climate change

Sector	Direct impact	Modelled	Risk	Ability to adjust or adapt	Comment	Likely economic consequence by 2100
Economy wide—international trade	Changes to import prices	Yes	High	–	Commodity-specific shocks, but methodology overlooks sectoral dimensions of climate change.	High
	Changes to world demand (commodity specific)	Yes	High	–		
Economy wide—infrastructure	Impacts on commercial buildings—changes to building codes and planning schemes	No	High	High	Capital stock of dwellings (current prices) in 2006–07 was around $1.3 trillion, 40% of total capital stocks (ABS 2007a).	Medium
	Accelerated degradation of buildings—maintenance and repair costs	Yes	High	High		Medium
Economy wide—extreme events (tropical cyclones, storms/flooding, bushfires)	Increased intensity of tropical cyclones—damage to residential infrastructure and home contents	Yes	High	Medium	The current average annual cost of tropical cyclones is estimated at $266 million, a quarter of the cost of natural disasters (BTE 2001).	Low
	Increased intensity of tropical cyclones—damage to commercial buildings and business interruption	No	High	Medium		Low
	Southward movement of tropical cyclones—infrastructure and business interruption	No	High	Medium	High uncertainty regarding southward movement of tropical cyclones.	Low
	Higher frequency of storm events (e.g. flooding from non-cyclone events)—damage to infrastructure	No	High	Medium in short run High in long run	Estimated average annual cost of floods in Australia is $314 million (BTE 2001).	Low
	Bushfires—infrastructure damage, crop loss, emergency response	No	High	Low–medium	Bushfires estimated to pose an annual average cost of about $77 million (BTE 2001).	Low
Economy wide—sea-level rise	Increase in sea levels of 0.59 m, impacts on coastal settlements	Yes	High	High	Assessment assumes there is no significant sea-level rise this century.	Low
Economy wide—human health	Heat-related stress, dengue fever and gastroenteritis—impacts on productivity	Yes	High	High	Assumes management and prevention of health impacts.	Low
	Other health impacts (productivity)	No	Low	High		Low
Agriculture	Changes in dryland crop production due to changes in temperature and CO2 concentrations	Yes	High	Medium	All crops $19.5 billion (gross value of commodities) (ABS 2007b).	High

Table 11.2 Assessing the market impacts of climate change *(continued)*

Sector	Direct impact	Modelled	Risk	Ability to adjust or adapt	Comment	Likely economic consequence by 2100
	Sheep, cattle, dairy—changes in carrying capacity of pasture from CO_2 concentrations, rainfall and temperature	Yes	High	Medium		High
	Impacts on sheep and cattle from heat stress due to temperature increases	No	Medium	Medium to high		Low
	Impacts on pigs and poultry from heat stress due to temperature increases	No	Low	Medium	Limited research on potential impacts.	Low
	Irrigated agriculture—reductions in water runoff	Yes	High	Medium	Adaptation through land-use change, water conservation.	High
Fisheries	Reduced yields due to changes in water temperature	No	Medium	Low	Potential for higher adaptive capacity for aquaculture. In 2004–05, fisheries contributed 0.14% of total GDP (ABS 2008a).	Low
Forestry	Yields affected by water availability and CO_2 concentrations	No	Low	Low	Possibility of using other species. In 2004–05, forestry contributed 0.12% of total GDP (ABS 2008a)	Low
Mining	Slower growth in demand due to slower increase in world income (relative to a world with no climate change)	Yes	High	Low	In 2006–07, the mining industry contributed 7% of total GDP (ABS 2007a). In the reference case, this is projected to be 10.2% in 2100.	Medium to high
	Reduction in water availability	No	High	High		Low

Table 11.2 Assessing the market impacts of climate change *(continued)*

Sector	Direct impact	Modelled	Risk	Ability to adjust or adapt	Comment	Likely economic consequence by 2100
Tourism	International tourism affected by slower growth in demand due to slower increase in world incomes (relative to a world with no climate change)	Yes	High	Low	Tourism as a share of GDP is 3.7%, which equates to $38 billion. In 2005–06, this was 10% of exports of goods and services (ABS 2008b).	Medium to high (highly uncertain)
	Reduction in international demand for Australian tourism as a result of reduced natural amenity of tourism products	No	High	Low	Requires assumptions of changes in preferences and relative amenity versus absolute amenity.	High
	Changes in domestic tourism as a result of reduced amenity of tourism products	No	Medium	Low to medium	Domestic tourism is worth $29 billion (2.6% of GDP) (relative to international tourism—$10 billion,0.9% of GDP). (ABS 2008B).	Low
Government (health)	Increased expenditure on prevention and treatment for dengue virus, heat stress and gastroenteritis	Yes	Medium	High	Public and private expenditure low to moderate.	Low
	Increased expenditure on prevention and treatment for other health impacts (air pollution, mental health etc.)	No	Medium	High		Low
Government (defence/aid)	Increase in defence and aid expenditure due to geopolitical instability in neighbouring nations	No	High	Low	Combined aid and defence budget for interventions in Timor-Leste and Solomon Islands, $900 million per year. Foreign aid 2006–07, 0.3% GNI (AusAID 2006). Defence expenditure 2006–07, $17 billion (ABS 2007c).	Medium to high (highly uncertain)
Residential dwellings	Building degradation and damage resulting from temperature, rainfall, wind etc. Changes to building codes and increased maintenance and repair	Yes	High	High	Costs of adaptation likely to be high.	High
	Impacts on buildings due to extreme events (e.g. flooding)	No	High	High	Costs of adaptation likely to be high.	Medium to high
Transport	Degradation of roads, bridges and rail due to temperature and rainfall	No	High	High	In 2004–05 maintaining and improving the total road network cost $9 billion (BITRE 2008).	Low

Table 11.2 Assessing the market impacts of climate change *(continued)*

Sector	Direct impact	Modelled	Risk	Ability to adjust or adapt	Comment	Likely economic consequence by 2100
Ports	Port productivity and infrastructure affected by gradual sea-level rise and storms	Yes	High	High		Low
Airports	Impacts on infrastructure due to sea-level rise, temperature and rainfall	No	Low	Medium		Low
Water supply	Decrease in rainfall reduces reliance on traditional water supply for urban use and increases demand for alternative water supply options	Yes	High	High	High costs associated with adaptation options.	Low to medium
	Degradation of water supply infrastructure increases maintenance costs	Yes	High	High		Low
Electricity transmission and distribution	Degradation of infrastructure increases maintenance costs Productivity losses from blackouts due to severe weather events	Yes	High	High	Net capital expenditure for electricity transmission and distribution was $6.2 billion in 2005–06 (ABS 2008e).	Low
Electricity generation	Increased demand for electricity resulting from greater use of air conditioners	No	High	High	New generation costs. Net capital expenditure for electricity generation was $2.8 billion in 2005–06 (ABS 2008e).	Low to medium

Note: High economic consequence implies 0.5–1.5% per cent loss of annual GDP by the end of the 21st century; medium economic consequence, 0.1–0.5 per cent; and low, less than 0.1 per cent.

The negative impacts of climate change on infrastructure have a significant effect on Australia's output and consumption of goods and services, and is responsible for about 40 per cent of total Type 1 GNP climate change costs.[6] The infrastructure impacts affect a wide range of assets, including commercial and residential buildings, water supply and electricity infrastructure, and ports.

By the end of the century, another 40 per cent of Type 1 GNP costs of climate change arise from the negative effect on our terms of trade. Coal demand is significantly lower than in the reference case, primarily as a result of the deceleration of global economic growth in response to climate change. The global modelling (GIAM) suggests that global GDP is likely to fall by around 8 per cent by 2100, with losses in developing countries likely to be higher than the global average. This is important for Australia as, by 2100, developing countries in Asia are projected to be overwhelmingly our major trading partners. The international modelling shows that Australian terms of trade are more adversely affected than those of any other country or region by climate change. By 2100, Australia's terms of trade are 3 per cent below the reference case, whereas for Japan, the European Union and the United States they are about 1 per cent below, and for Canada 0.5 per cent above.

About 20 per cent of Type 1 GNP costs arise from the direct climate change impacts on agriculture. The loss of agricultural productivity as a result of climate change results in agriculture drawing more resources from the rest of the economy in order to meet an assumed inelastic demand for agricultural products, and to maintain production at levels determined by domestic and world demand and prices.[7]

Agriculture is hit particularly hard by climate change. Agricultural activity is reduced by more than 20 per cent relative to the reference case. These impacts would be unevenly distributed. Without mitigation, the best estimate for the Murray-Darling Basin is that by mid-century it would lose half of its annual irrigated agricultural output (Chapter 6). By the end of the century, it would no longer be a home to agriculture.

The other sector that is hit hard is mining. Output of this sector is projected to decline by more than 13 per cent by 2100. This result is mainly driven by the deceleration of global economic growth. Most coal produced in Australia is exported. The international modelling implies that the world demand for coal falls by almost 23 per cent.[8] Iron ore activity declines for much the same reason as for coal.

The health-related impacts considered by the Review are estimated to have relatively small market effects, though this does not take into account the intrinsic value of the lives lost.

The economic effects of tropical cyclones, taken as a series of annualised losses, are estimated to be small. While a single cyclone event has the potential to create significant economic damage, particularly if it were to hit a population centre, these events are, and are likely to remain, relatively infrequent. These results may be underestimated, however, as it was not possible to consider either the impacts of flooding associated with cyclones or the impacts that might be associated with a southward shift in the genesis of tropical cyclones.

Estimating and incorporating Type 2 costs: non-modelled expected market impacts

The second type of cost, Type 2, covering the expected market costs of the median outcome of impacts for which data are too unreliable to feed into general equilibrium modelling, are estimated at about 30 per cent the size of the Type 1 GNP costs (see Box 11.2). Taken together, Type 1 and Type 2 costs amount to approximately 8 per cent of GDP, about 10 per cent of GNP and consumption, and a higher percentage of and real wages.

Box 11.2 Estimating Type 2 costs of climate change

Table 11.2 identifies some major expected (median case) market impacts of climate change this century, indicating which ones were included in the modelling and which were excluded, and provides a qualitative assessment of their importance in terms of market effects. The following market impacts were judged to be significant, but could not be included in the modelling, mainly because of lack of data.

There will probably be additional increases in the cost of **building construction** as a result of new building design requirements, in addition to those that have been modelled, as well as increased **road and bridge maintenance** costs. Based on the value of the building capital stock and road network in Australia, the effects of climate change on building infrastructure and roads and bridges that have not been estimated could subtract an additional 0.8 and 0.25 percentage points respectively from GDP by the end of the century.[9] The need for increased peak power usage to cool buildings could also be a significant omission.

The modelled impacts on **agriculture** are based on average changes to climate variables. It is likely that climate change will also affect the variability and predictability of the climate (especially rainfall). In the absence of forecasts describing the level of future variability, it is difficult to provide an estimate of the degree to which increased climate variability would affect the economy.

International tourism will be affected by climate change. The Review has captured the impact of climate change on tourism through incomes and relative prices, but not through the deterioration of environmental assets. Some major environmental assets that are important for Australian tourism are highly susceptible to climate change. These include the Great Barrier Reef, south-western Australia (a biodiversity hotspot) and Kakadu (see Chapter 6). International travel to Australia is projected to increase substantially in the reference case as global incomes rise strongly over the coming decades. This suggests that even small changes in demand could have significant economic implications for Australia.

Box 11.2 Estimating Type 2 costs of climate change *(continued)*

Climate change may lead to **geopolitical instability**, which will require an increase in the capability and requirements of Australia's defence force and an increase in the level of Australia's spending on emergency and humanitarian aid abroad. Previous Australian interventions in small neighbouring nations provide some indication of the potential size of future defence costs that may arise from climate change. The combined aid and defence budget for the five-year intervention in Timor-Leste has exceeded $700 million per year. Australia's intervention in Solomon Islands is estimated to cost around $200 million per year (Wainwright 2005). This level of intervention is likely to continue until at least 2013. Climate change could lead to the involvement of larger countries through geopolitical pressures, and thus may lead to much higher spending than would be indicated by recent history. A 10 per cent increase in defence spending would be a cost of 0.2 per cent of GDP. Although extra defence spending does not automatically lead to reduced GDP, the Review treats it as a cost since it represents resources that would otherwise have been available for productive use elsewhere.

To summarise, the omitted impacts on infrastructure and defence alone could subtract an additional 1.2 per cent from GDP (or GNP, the main modelling output reported) at the end of the century. The effects on tourism, variability and predictability effects on agriculture, additional impacts of geopolitical instability on Australia, and the range of other possible impacts noted in Table 11.2 need to be added to this. The total omitted market impacts could contribute an additional 1 to 2 percentage points to the loss of GNP at the end of the century, taking the estimated Type 2 loss to between 2.2 and 3.2 per cent. This would imply that the modelling has captured 77 to 70 percentage points of the 2100 no-mitigation cost to GNP. Applying only the upper bound of this range implies that Type 2 costs are about 30 per cent of the Type 1 costs of climate change.

In comparative costings of the three scenarios analysed in this chapter, it is assumed that this relationship holds not only for 2100 and the no-mitigation scenario, but for the entire century and for all three scenarios. This approach is clearly based on a significant degree of judgment and simplification. However, the inclusion of Type 2 costs is considered to be crucial to an appropriate evaluation of the expected market effects of climate change and the corresponding benefits from mitigation. The Review considers these estimates to be conservative.

These combined end-of-century Type 1 and Type 2 costs are much higher than estimates from earlier quantitative studies of the global costs of climate change during the 21st century. Stern (2007), for example, found a reduction in global GDP per capita as a result of climate change of only 2.9 per cent in 2100 after taking into account all four of the categories of costs described above, two of which (types 3 and 4) are excluded from the calculations in the preceding paragraph.

The earlier and larger costs of climate change in the Review's study derive in substantial part from the application of realistic, Platinum Age assessments of the growth in emissions in the absence of mitigation (Chapter 3).

One main theme of the Review is that the accelerated growth of the developing world, the Platinum Age, has not been factored into expectations of emissions, concentrations or temperatures. This growth, centred on but now extending well beyond China, is unprecedented, and likely to be sustained over a considerable period.

The Fourth Assessment Report of the IPCC presented a range of best-estimate temperature increases for this century from 1.8 to 4°C (or from pre-industrial levels, 2.3 to 4.5°C) (IPCC 2007: 13). The Review has generally accepted the scientific judgments of the IPCC, on a balance of probabilities, as a reasonable source of scientific knowledge on climate change. But the economic analysis of the IPCC rests on work from the 1990s, which the Review has shown to have been overtaken by events. Chapter 3 shows that the IPCC's SRES scenarios, on which its projections of climate change impacts were based, systematically underestimate the current and projected growth of emissions. Far from being alarmist, it is simply realistic to accept the conclusion from analysis that, if the mainstream science is roughly right, then 1.8 to 4°C can no longer be accepted as the central range for temperature increases in the 21st century under business as usual. Instead, that range should centre around 5°C.

Costs of catastrophic climate change (Type 3)

The rapid growth in emissions associated with the Platinum Age has an unfortunate consequence: in the absence of mitigation, it is making outcomes likely that were once seen as having low probability. The economist Martin Weitzmann justifies strong mitigation action on climate change on the basis of prevention of a possible catastrophic outcome. A recent article (Weitzmann 2007: 18) specifies a 3 per cent probability that temperatures will increase by 6°C by the end of the century, the result of which will be:

> a terra incognita biosphere within a hundred years whose mass species extinctions, radical alterations of natural environments, and other extreme outdoor consequences of a different planet will have been triggered by a geologically instantaneous temperature change that is significantly larger than what separates us now from past ice ages.

How much stronger, then, is the justification for mitigation when the probability of a temperature increase in the range of 6°C is not 3 per cent, but nearly 50 per cent (recall that the no-mitigation best estimate for temperature increase by century's end is 5.1°C)? This is the order of the change of probabilities for such a temperature increase once we move from the now-outdated SRES scenarios on which Weitzmann bases his 3 per cent calculations, to the more recent and realistic projections of emissions reported in Chapter 3.

The end-of-century temperature increase expected from the no-mitigation scenario is above the estimated range of 'tipping points' for seven of the eight catastrophic global events (enumerated in section 11.5) for which Lenton et al. (2008) present such a range, and it is at the top end of the range for the eighth.

That catastrophic events have become more likely does not make them more amenable to modelling. Table 4.1 presented results from a survey of the recent scientific literature. This indicated that, given the best estimate for climate sensitivity, the triggering of a large-scale melt of the Greenland ice sheet under temperatures expected by the end of century in a no-mitigation scenario would be a sure thing. Given the uncertainties of when the melt would start, and when it would translate into sea-level rises, the effect has been neither modelled nor included in our Type 2 estimates of the costs of climate change. As the sea level rose over a matter of centuries by 7 m, there would certainly be a large negative impact on the world, and on Australia, through the risks of severe and possibly catastrophic effects on non-market values and on the basis of median expectations of market impacts. These would also be the conditions under which irreversible melting of the west Antarctic ice sheet would be most likely to occur, so that the correlation of risks increases the chance of severe outcomes.

Non-market (Type 4) costs

The non-market risks of climate change will be significant in a no-mitigation scenario. As Table 4.1 shows, at the high levels of temperature increase expected under the no-mitigation scenario, 88 per cent of species would be at risk of extinction, and coral reefs as we know them would be destroyed. In the Australian context, under the no-mitigation scenario, by halfway through the century the Great Barrier Reef would be destroyed, and by the end of the century the Kakadu wetland system would be inundated by sea water. Non-market impacts also include the greater number of deaths due to hotter weather, the inconvenience of a greater number of extremely hot days, and much higher bushfire risk.

While there are methods through which non-market impacts can be monetised, the Review found it more useful simply to identify them, and to note that, as incomes and consumption rise, as is anticipated in the no-mitigation scenario, the relative value people assign to non-market costs and benefits will rise as well.

Costs beyond the 21st century

The lags and non-linearity of climate change impacts, even looking only at the expected market impacts, is reflected in the Review's modelling. The gradient of the modelled market impacts of the unmitigated scenario (Figure 11.2) at 2100 indicates that the costs of unmitigated climate change would grow rapidly into the 22nd century. The estimated impacts in the unmitigated scenario increase threefold from 2050 to 2075, and then threefold again from 2075 to 2100. This rate of increase in damages far outstrips the projected rate of increase in temperatures. It is obvious that if the analysis were continued into the 22nd century, estimated market impacts from climate change would be dramatically higher than for the latter decades of the 21st century.

Other studies of climate change show much higher costs in the next than in the current century. Cline (2004) used a modified version of Nordhaus's climate change model going out to the year 2300. Cline's emissions growth is lower than in the Review's modelling, but a scenario with a higher climate sensitivity yields temperature outcomes close to the Review's no-mitigation scenario at 2100, and temperature continues rising to a 15°C increase at 2300. In Cline's scenario, climate change damages as a percentage of global GDP are 9 per cent by 2100, about 25 per cent by 2200, and a remarkable 68 per cent by 2300.

The Stern Review attempted a more comprehensive assessment of global climate change damages, including market as well as non-market impacts and a probability distribution over a range of possible outcomes to 2200. Stern's analysis shows impacts on expected per capita consumption at 3 per cent at 2100, rising to 14 per cent at 2200.

As discussed in Chapter 1, under reasonable assumptions, the present value of a percentage point of Australian GNP in a century's time is about as high as a percentage point of GNP this century. The Review has not tried to model climate change impacts beyond the 21st century. It is clear that they matter.

Summary of unmitigated climate change costs

There is a risk that temperature increases, and therefore all the impacts that are related to temperature, will be much greater than anticipated in the standard cases of the modelling because of positive feedback effects. These are difficult to quantify, but they are real and potentially significant. Once temperature increases above certain threshold points, massive carbon and methane stores on earth and in the oceans may be destabilised, leading to much greater volumes of greenhouse gas release from the natural sphere, and further temperature increases.

To summarise, temperature increases of the order of magnitude associated with no mitigation—an expected increase by 2100 of 5.1°C, a 6.6°C warming at the top of the likely band, and a smaller probability of a double-digit temperature increase—would not lead to a marginal reduction in human welfare. Their impacts on human civilisation and most ecosystems are likely to be catastrophic. As the Center for Strategic and International Studies recently noted in its study of climate change scenarios, this extent of climate change 'would pose almost inconceivable challenges as human society struggled to adapt… The collapse and chaos associated with extreme climate change futures would destabilize virtually every aspect of modern life' (Campbell et al. 2007: 7, 9).[10]

To point to the devastating impact of temperature increase for this century, and of significant further increases next century, and to the possibility that such increases would leave both global and Australian welfare at the end of this century lower than at the start, is not to be alarmist. It is simply to recognise the reality of rapid emissions growth, its likely continuation in the absence of climate change mitigation, and the possibly catastrophic consequences of such large, rapid temperature increases.

11.4.2 The costs of avoiding unmitigated climate change

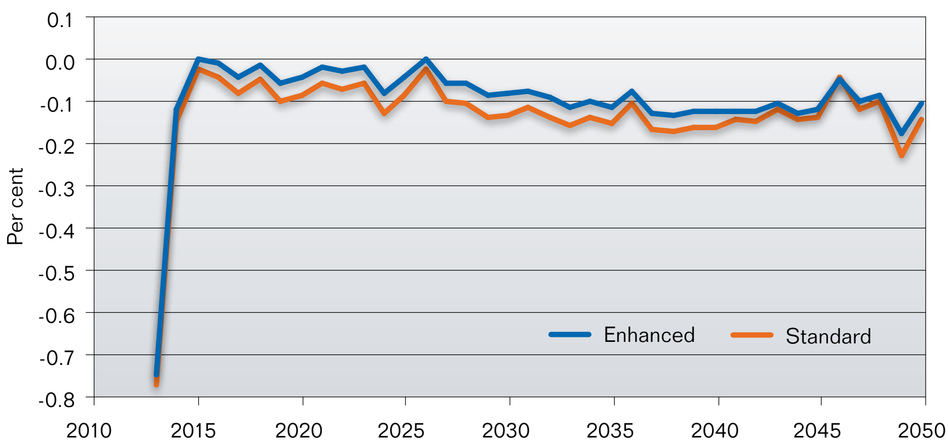
How much would it cost to greatly reduce the extensive climate change damage outlined in the previous section? Figure 11.3 depicts the costs of mitigation up to 2050 under stabilisation at 550 ppm, as implemented in GTEM (Box 11.1). The results are shown under both standard and enhanced assumptions concerning technological progress, as discussed in section 11.3.[11]

After an initial modelled shock to GNP growth of around 0.8 percentage points (a cost which in reality would be spread over several years), the gross costs of mitigation as modelled in GTEM typically shave a bit above 0.1 per cent per annum from GNP growth until after the halfway mark in the century under standard technology assumptions and a bit below 0.1 per cent per annum under enhanced technology assumptions. This can be seen as sacrifice of material consumption in the early decades.

The gap between the standard and enhanced cases opens up in the second half of the century. On average, annual GNP growth is 0.07 per cent faster in the enhanced case than in the standard, and the economy actually grows marginally faster in the enhanced case with mitigation than without. (The enhanced technology case is further explored in chapters 21 and 23.)

Modelling the costs of mitigation in the second half of the century is more complex, for two reasons. First, as discussed earlier, technological options become more uncertain. It is unrealistic to expect that carbon prices will continue to rise beyond many hundreds of dollars (as in Figure 11.1) without the development of new technologies to offset emissions. Accordingly, long-run cost modelling is best undertaken with the assumption that at some price a backstop technology

Figure 11.3 Change in annual Australian GNP growth (percentage points lost or gained) due to gross mitigation costs under the 550 scenario strategy compared to no mitigation, and under standard and enhanced technology assumptions, 2013–50



Note: Results are from GTEM (Box 11.1). For details on the standard and enhanced variants of GTEM, see section 11.3.

develops, even if there is uncertainty about the price at which that technology will develop and the precise form it will take.

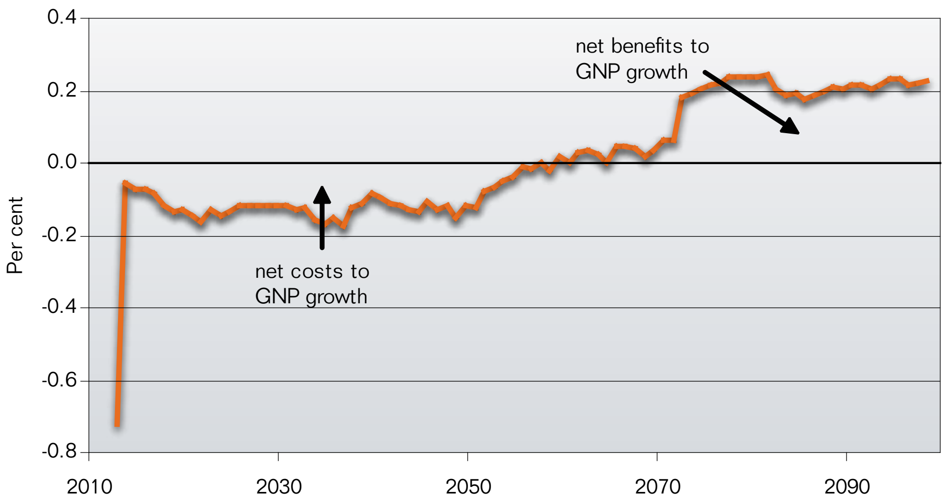
Second, avoided expected climate damages become significant, so measures of costs without them (such as modelled in GTEM) become less informative. The net mitigation costs calculated in MMRF take into account both the gross costs of mitigation and the benefits of avoided expected climate change market impacts (the Type 1 costs). In addition, the net costs shown here make an adjustment for the Type 2 costs of climate change, along the lines developed for the no-mitigation scenario.

These net costs of mitigation as modelled and accounted for here are not meant to represent the full benefits of mitigation, as they do not seek to capture the Type 3 and Type 4 and post–21st century benefits of mitigation. They do, however, provide an indication of the amount Australia would need to pay to have access to the additional benefits of climate change mitigation.

Figure 11.4 shows the net cost of mitigation (including expected market costs as well as benefits) for the 550 scenario, using the MMRF model with an extension implemented by the Review to allow for a backstop technology to emerge post 2050.

Figure 11.4 shows that, in the second half of this century, mitigation towards the 550 reduction target adds to the growth rate of the economy, as, at the margin, more new climate change damages are avoided than new mitigation costs added. In fact, by the end of the century, GNP is higher than it would have been without mitigation, even when all the costs and only the expected market benefits (avoided costs types 1 and 2, but not types 3 and 4) of mitigation are taken into account.

Figure 11.4 Change in annual Australian GNP growth (percentage points lost or gained) due to net mitigation costs under the 550 scenario compared to no mitigation, 2013–2100

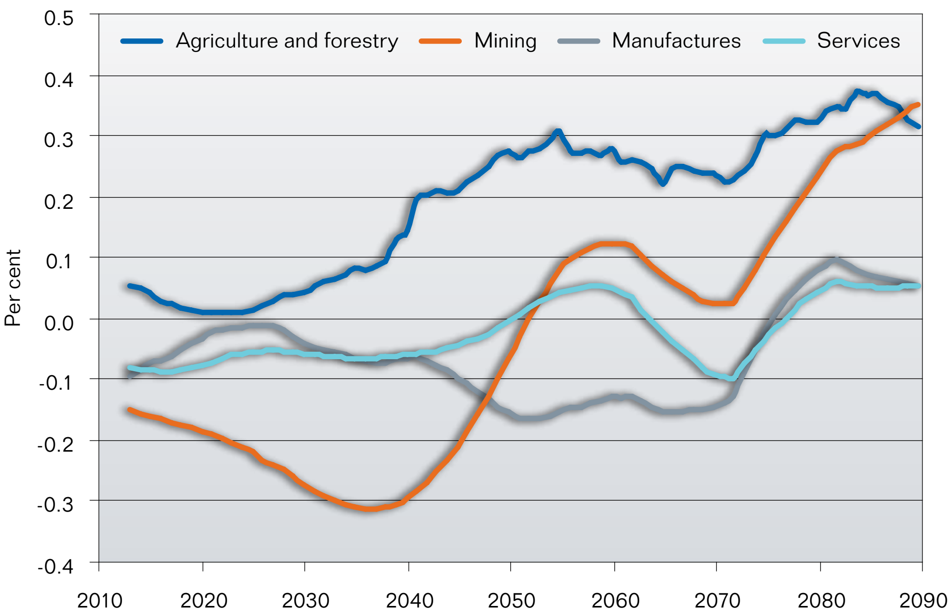


Note: The figures reflect results modelled in MMRF (Box 11.1) adjusted to incorporate Type 2 costs using the method described in Box 11.2.

Figure 11.5 tells this story by sector. At the aggregated industry level, the big winner from mitigation is the agriculture and forestry sector, which in the second half of this century is growing about 0.3 per cent faster on average every year, as forestry expands and less climate change damage is imposed on agricultural productivity. Mining does worse with mitigation in the first half of the century, but better in the second as the terms of trade improve. Growth in manufacturing and services is little affected by mitigation.

The terms of trade effects of mitigation are ambiguous. On the one hand, reduced climate change damage improves the terms of trade; on the other, a swing away from fossil fuels associated with global mitigation harms them. Under standard technology assumptions, the net impact is a further worsening of the terms of trade (from 3 per cent below the reference case in the no-mitigation scenario to 4 per cent below in the 550 scenario in 2100). But under enhanced technology assumptions, where clean coal technology is more competitive, the terms of trade in 2100 are 2 per cent above the reference case. Likewise, the backstop technology improves terms of trade to 1 per cent above the no-mitigation scenario.

Figure 11.5 Change in Australian sectoral growth rates (percentage points lost or gained) due to net mitigation costs under the 550 scenario compared to no mitigation, 2013–2100



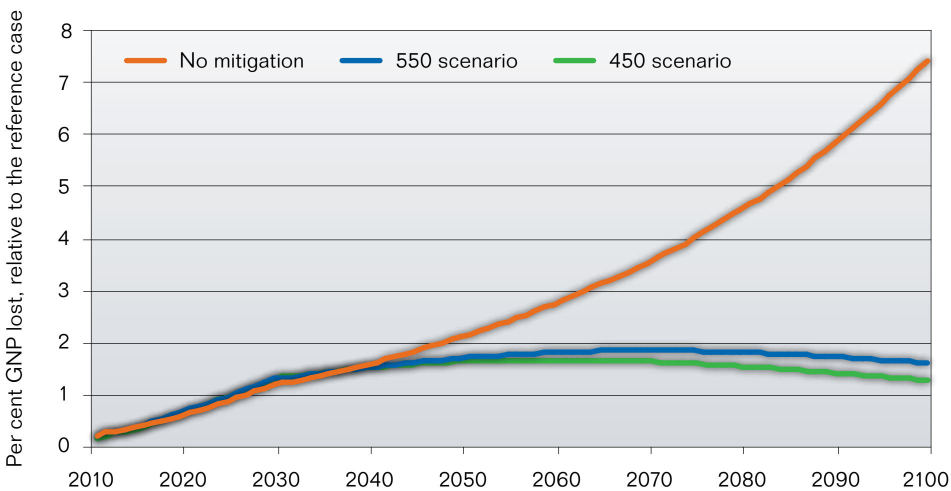
Note: Sectoral growth rates are the growth in sectoral activities (value added), as modelled in MMRF. Only Type 1 costs are shown here. Ten-year forward moving averages are used to smooth annual variability. Growth rates are presented for aggregated sectors under the backstop technology case. Uncertainty regarding the backstop technology was recognised by applying costs evenly across all sectors, and reducing emissions from all sources. Any actual backstop technology would likely have a differential impact on sectoral growth. It is therefore not possible to project sectoral changes with a high degree of certainty in the second half of the century.

Despite the boost to growth in the second half of the century, the sacrifice in the first half is substantial, even though the loss to the annual level of GNP is fully recovered with a margin by the end of the century. Of course, stabilisation at 550 ppm does not eliminate all costs associated with climate change. Temperatures would still be expected to increase by 2°C over the course of the century, with associated risks. Nevertheless, the benefits that are purchased by the cost of the 550 strategy are substantial, and take several forms.

One is insurance against the effects of severe and possibly catastrophic outcomes on material consumption during this century. Another is increased protection against loss of non-market services this century. Yet another is avoidance of all of the rapidly increasing costs throughout the 21st and into the 22nd century and beyond: the rapidly increasing negative impact on material consumption under median outcomes (types 1 and 2); the risk of outcomes much worse than the median expectations from the applied science (although throughout and beyond the 21st century the median outcomes are more severe and possibly catastrophic) (Type 3); and the impacts on non-market values (Type 4).

Figure 11.6 compares expected market damages from climate change under temperatures that would be expected for a 550 scenario with those damages associated with temperatures expected under a no-mitigation scenario (see Figure 11.2). Climate damages under the 450 scenario are also shown for later reference. This figure makes for an incomplete comparison for all the reasons

Figure 11.6 A comparison of the modelled expected market costs for Australia of unmitigated and mitigated climate change up to 2100 (Type 1 costs only)



Notes: The graphs show the cost as a percentage of GNP of expected market damages from the level of climate change associated with the three scenarios. These estimates are achieved by 'shocking' the reference case with the differing levels of impact associated with the temperatures expected from the three scenarios.

already cited, but it is a telling one. Market damages under the 550 scenario flatten, stabilise and begin to decline relative to GNP by the end of the century, just as market damages under the no-mitigation scenario start to accelerate markedly. The choice is between a future with bounded expected climate change costs, but still significant risks, and one with unbounded expected costs, a high probability of severe outcomes and some chance of outcomes that most Australians would consider to be catastrophic.

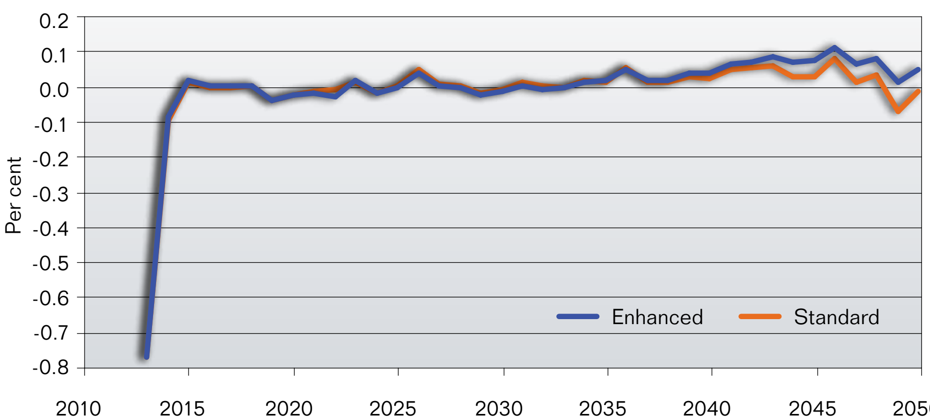
The rapid growth in global emissions is increasing the costs both of mitigation (Gurria 2008) and of no mitigation. The costs of well-designed mitigation, substantial as they are, would not end economic growth in Australia, its developing country neighbours, or the global economy. Unmitigated climate change probably would.

11.5 How much mitigation?

Is it in Australia's interest to support a global goal of limiting the concentration of greenhouse gases to 450 ppm CO_2-e, or lower, rather than 550 ppm? A major portion of the Review's modelling went into weighing the relative benefits of Australia's participation in a 450 ppm and 550 ppm global climate change mitigation agreement.

Figures 11.7 and 11.8 present the same comparison in terms of growth rates as in Figures 11.3 and 11.4 above, but this time comparing 450 and 550 scenarios rather than no-mitigation and 550.

Figure 11.7 Change in annual Australian GNP growth (percentage points lost or gained) due to gross mitigation costs under the 450 compared to the 550 scenario and under standard and enhanced technology assumptions, 2013–50

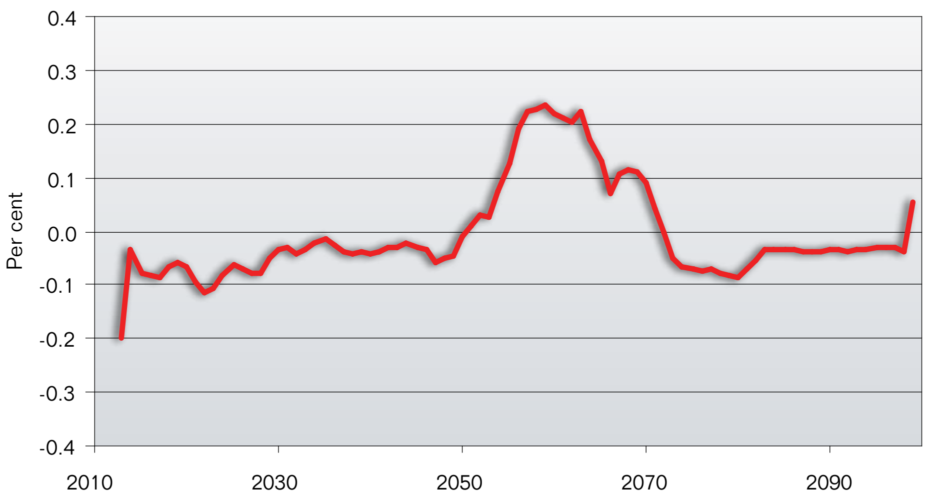


Note: Results are from GTEM (Box 11.1). For details on the standard and enhanced variants of GTEM, see section 11.3.

In GTEM, there is an additional growth penalty when the 450 regime is introduced (though again, this would be spread over several years), but after that there is no real growth differential between the 450 and 550 scenarios, whichever set of technological assumptions is made.

Net mitigation costs modelled in MMRF (Figure 11.8), with the backstop technology as before, show greater volatility in the growth differential between the 450 and 550 mitigation scenarios over the full century than GTEM does for gross mitigation costs in the first half of the century. Overall, however, the story is a similar one. After the initial shock, there is, on average, no difference in the GNP growth rates under the two scenarios over the course of the century. Sectoral differences in growth rates under the two mitigation scenarios are relatively minor under backstop technology assumptions. Gains to agriculture and manufacturing are offset by losses to mining. Sectoral differences under different technology assumptions are explored in chapters 20 to 22.

Figure 11.8 Change in annual Australian GNP growth (percentage points lost or gained) due to net mitigation costs under the 450 compared to the 550 scenario, 2013–2100



Note: The figures reflect results modelled in MMRF (Box 11.1) adjusted to incorporate Type 2 costs as per the method described in Box 11.2. Since annual differences in the 550 and 450 growth rates show considerable volatility, they are smoothed in this graph by using a three-year forward moving average.

Table 11.3 summarises the cost differences between these two scenarios. It presents results using the GTEM model for gross mitigation costs out to 2050 (where avoided climate damages are small), and the MMRF model (with the post-2050 backstop) for net mitigation costs (costs net of Type 1 and Type 2 benefits).

It calculates the net present value of these costs using two discount rates the Review considers appropriate, namely 1.4 and 2.7 per cent (as derived in Chapter 1).

At the bottom of the range of discount rates considered (1.4 per cent), and for both models, and both time periods and methods, the net present value of the excess cost of the 450 over the 550 scenario (the '450 premium') is 0.7 to 0.8 per cent of discounted GNP. At the top end of the range of discount rates (2.7 per cent), the premium is in the range of 0.7 to 0.9 per cent of discounted GNP.

Table 11.3 Net present cost of the 450 ppm and 550 ppm scenarios (in terms of no-mitigation GNP) and the '450 premium' to 2050 and 2100

Discount rate equals 1.4%	550	450	450 premium
Gross mitigation cost to 2050 (per cent)			
GTEM standard	2.6	3.3	0.7
GTEM enhanced	1.9	2.6	0.7
Net mitigation cost to 2100 (per cent)			
MMRF	3.2	4.0	0.8
Discount rate equals 2.7%	**550**	**450**	**450 premium**
Gross mitigation cost to 2050 (per cent)			
GTEM standard	2.4	3.2	0.7
GTEM enhanced	1.8	2.5	0.7
Net mitigation cost to 2100 (per cent)			
MMRF	3.3	4.2	0.9

Note: The figures give the discounted costs as a percentage of discounted GNP. The '450 premium' is the excess of the 450 ppm cost over the 550 ppm cost. Costs in GTEM are gross costs of mitigation; costs in MMRF are net costs (gross costs net of Type 1 and Type 2 benefits). MMRF modelled results are adjusted to incorporate Type 2 costs using the method described in Box 11.2.

Figure 11.6 helps to explain why the 450 scenario is always the more expensive one in terms of modelled results. Expected climate change damages are less in the 450 scenario than in the 550 scenario, but only by half a per cent of GNP. The small expected market gain from the 450 scenario to 2100 is not in itself adequate to justify the additional mitigation costs associated with it. Rather, the large difference between 450 and 550 scenarios is in terms of additional Type 3 and Type 4 avoided costs. What are the non-market (Type 4) and insurance (Type 3) benefits of a 450 relative to a 550 outcome?

Differential avoidance of non-market climate change impacts

Neither strategy will lead to the complete avoidance of non-market climate change–related impacts. Chapter 6 found that even an increase of 1°C could result in a 50 per cent decrease in the area of rainforests in North Queensland.

Nevertheless, the analysis suggests that the difference between a 450 and a 550 outcome could be of major significance for a range of environmental impacts. For example:

- A 550 outcome would be expected to lead to the destruction of the Great Barrier Reef and other coral reefs as we recognise them today. The 450 outcome would be expected to damage but not destroy these coral reefs. Under a 550 scenario, the three-dimensional structure of the corals would be largely gone and the system would instead be dominated by fleshy seaweed and soft corals. At 450 ppm, the reef would still suffer—mass bleaching would be twice as common as it is today—but its disappearance would be much less likely (Table 6.2).
- The 550 ppm outcome would lead to a greater incidence of species extinction. Under the expected temperature outcome from the 550 ppm scenario, 12 per cent of species are predicted to be at risk of extinction. This percentage is reduced to almost 7 per cent under the 450 scenario (Table 4.1).

Differential insurance value of the 450 ppm and 550 ppm scenarios

As important as these differential non-market impacts are, perhaps the decisive advantage of the 450 scenario over the 550 is its insurance value. While neither scenario would eliminate climate change risks, the 550 scenario would leave the world, and Australia, open to larger risks of exceeding threshold temperature values, even if these tipping points cannot be known in advance with certainty. Lenton et al. (2008: 1786) identified nine important 'tipping elements' ('subsystems of the Earth system that are at least subcontinental in scale and can be switched—under certain circumstances—into a qualitatively different state by small perturbations'), and conducted a survey of experts to estimate the associated temperature tipping points. For one of the nine (disruption of the Indian summer monsoon), the tipping point could not be identified. For two—melting of the Arctic summer sea ice and the Greenland ice sheet—the tipping point range was put at below 2°C (above 1990 levels). For the other six, the tipping point ranges all start at 3°C and extend to 4, 5 or 6°C. These six are melting of the west Antarctic ice sheet, disruption of the Atlantic thermohaline circulation, disruption of the El Niño – Southern Oscillation, disruption of the Sahara/Sahel and West African monsoon, dieback of the Amazon rainforest, and dieback of boreal forest.

What is the probability of reaching that 3°C degree threshold? Under the 550 scenario, 2.7°C is within the likely (two-thirds probability) range of temperatures at 2100, and 3.1°C by 2200. High-end probabilities are difficult to define for climate sensitivity, but, as reported in Chapter 2, the IPCC notes that '[v]alues substantially higher than 4.5°C [which is at the upper end of the likely range] cannot be excluded' (IPCC 2007: 12). This means there would be a smaller but still significant (say 10 per cent) probability that the 550 scenario could produce a temperature increase in excess of 3°C over 1990 levels by the end of the century. This could also happen under the 450 scenario, but even at the top end of the likely range, the increase in this scenario is 2.1°C at the end of this century.

To give just one comparison, according to the estimates in Table 4.1 the temperature increase expected from the 550 scenario would give a 26 per cent probability of initiating large-scale melt of the Greenland ice sheet. The temperature increase expected from the 450 scenario would give a 10 per cent probability.

The large temperature changes associated with the higher end of the 550 scenario probability distribution, and the tipping points that this might breach, could have far-reaching consequences. A Center for Strategic and International Studies study of climate change scenarios (Campbell et al. 2007), referred to earlier in this chapter, included a scenario of 'severe climate change', within which temperatures increased by 2.6°C over 1990 levels by 2040. In the 550 ppm scenario modelled by the Review, this is not far above the top end of the likely range by 2050 (see Table 11.1). The study found that, under this scenario:

> nations around the world will be overwhelmed by the scale of change and pernicious challenges, such as pandemic disease. The internal cohesion of nations will be under great stress … both as a result of a dramatic rise in migration and changes in agricultural patterns and water availability. [There will be] flooding of coastal communities around the world ...

Is it worth paying less than 1 per cent of GNP more through the 21st century for the insurance value and the avoided market and non-market impacts of the 450 scenario?

This is a matter of judgment. Judgment will be affected greatly by the success of mitigation regimes and progress in research, development and commercialisation of low-emissions technologies over the years ahead. The Review thinks it likely that, with a significant and rising carbon price and support for emergence of low-emissions technologies, and confidence that the new policies are permanent features of the economic environment, there will be technological progress in areas not currently anticipated. Such developments would greatly favour a 450 outcome over a 550 outcome.

Given the benefits after 2200 of stronger mitigation and the greater risks of catastrophic consequences to the natural environment under the 550 scenario, the Review judges that it is worth paying less than an additional 1 per cent of GNP as a premium in order to achieve a 450 result.

Note, however, that Australia is not in a position to achieve 450 ppm CO_2-e on its own. Chapter 9 concluded that a credible agreement to secure the 450 scenario looked difficult for the international community as a whole in the year or two immediately ahead. Chapter 12 discusses how Australia can most effectively pursue support for a 450 global mitigation strategy in these inauspicious circumstances.

Notes

1 The global emissions path is determined within the global modelling (GTEM) using a Hotelling-style carbon price function. The start price is fixed and then increases over time at the prescribed interest rate of 4 per cent. The real interest rate is assumed to be 2 per cent. This is adjusted upwards by a 2 per cent risk premium. This approach provides a proxy for banking and borrowing, and imitates an efficient intertemporal distribution of abatement effort. The resulting emissions pathway is then used for international trading simulations. The concept of a resource price rising with the interest rate comes from resource economics. Hotelling (1931) demonstrated that profit from the optimal extraction of a finite mineral resource will increase over time at the rate of interest. Since only a finite amount of greenhouse gases can be released into the atmosphere prior to stabilisation, the optimal release of greenhouse gases into the atmosphere over time is a problem similar to the optimal extraction of a finite resource (Peck & Wan 1996).

2 The standard technology assumptions represent a best estimate of the cost, availability and performance of technologies based on historical experience, current knowledge and expected future trends. The standard scenario includes some technological cost reductions through learning by doing and improvements in existing technologies and the emergence and wide-scale deployment of some currently unproven technologies such as carbon capture and storage, hot rocks (geothermal) and hydrogen cars. It does not, however, include a backstop technology in any sector.

3 Specifically, the enhanced scenario implemented in GTEM included the following assumptions:

- Faster energy efficiency improvements of an extra 1 per cent annually from 2013 to 2030, an extra 0.5 per cent from 2031 to 2040 and no extra improvements thereafter.
- More effective carbon capture and storage in response to higher carbon prices. The share of combustion CO_2 captured increases from 90 per cent to 99 per cent as the permit price rises from zero to \$140/t CO_2-e.
- Faster learning by doing for electricity and transport technologies by increasing the parameter for the learning functions by 50 per cent relative to the standard assumptions over the whole simulation period.
- Non-combustion agricultural emissions are eliminated when the carbon price exceeds \$250/t CO_2-e.

4 For technical reasons, it was necessary for the Review to use different global average temperature changes for the assessment of domestic impacts than for the assessment of international climate change impacts. For the Australian impact analysis, median rainfall and local temperature outcomes are assumed in response to an average global temperature change of 4.5°C degrees by 2100 (above 1990 levels). This temperature change is based on the A1F1 SRES (see Chapter 3). This temperature change differs from the temperature estimated based on the Garnaut–Treasury global emissions profile used in the economic modelling. This emissions profile gives an increase in global average temperature of 5.1°C degrees by 2100 (above 1990 levels). These differences could not be avoided in the time frames available for the Review.

5 The terms of trade describe the ratio of export to import prices.

6 This decomposition is obtained by running each of the five shocks separately. Due to interactive general-equilibrium effects, the decomposition is not exact.

7 The extent to which imports replace domestic food production is limited. Two factors are influential here. First, growth in developing countries, combined with land constraints, exacerbated by climate change, is likely to result in increases in the cost of food produced overseas over the next 100 years. Second, while the Review has not undertaken detailed modelling to estimate the impacts that climate change may have on the cost of food

production in the rest of the world, any change is presumed to influence the availability of food exports to Australia.

8 Caution needs to be exercised in interpreting changes to world demand. A 23 per cent decline implies that, with prices fixed, exports will decline by 23 per cent. However, prices are not fixed in MMRF. With a typical export price elasticity of around 5, small changes to prices will change the export results.

9 An increase in the cost of constructing and maintaining buildings is equivalent to a productivity loss since more capital inputs per unit of output would be required. If buildings make up around 40 per cent of capital stocks, and capital incomes make up approximately 40 per cent of total income, then a 5 per cent reduction in productivity of the building stock would be expected to reduce GDP by approximately 0.8 per cent. In 2004–05, the cost of maintaining and improving the road network was $9 billion (Table 11.1). If the cost of maintaining the road network were to increase by 25 per cent, GDP might be reduced by around 0.25 per cent.

10 The report was prepared by, among others, former CIA Director James Woolsey, former Chief of Staff of the President John Podesta, former National Security Advisor to the Vice President Leon Fuerth, Pew Center Senior Scientist Jay Gulledge, and former Deputy Assistant Secretary of Defence for Asia and the Pacific Kurt Campbell.

11 Due to the modelling procedures followed, and the different models employed by the Review, the emissions entitlement allocations for Australia modelled in GTEM were slightly different to those presented in Chapter 9 and modelled in MMRF: over the century, a 1 percentage point greater reduction from the reference case for the 550 scenario (82 compared to 81 per cent), and a 2 percentage point greater reduction for the 450 scenario (88 compared to 86 per cent). The Chapter 9 (and MMRF) allocations are more generous early on, and less generous later than the ones in GTEM. Simulations suggested very little difference in cost over time. A partial equilibrium adjustment to account for the differential purchase of emission permits made no discernible difference in the growth rates over time. There is, however, a difference in the first year, where the GTEM allocation profile exaggerates the negative shock on GNP. See the technical appendix on the modelling at <www.garnautreview.org.au> for further discussion.

References

ABS (Australian Bureau of Statistics) 2007a, *Australian System of National Accounts, 2006–07*, cat. no. 5204.0, ABS, Canberra.

ABS 2007b, *Australian Farming in Brief, 2007*, cat. no. 7106.0, ABS, Canberra.

ABS 2007c, *Government Finance Statistics*, cat. no. 5512.0, ABS, Canberra.

ABS 2008a, *Australian National Accounts: Input – Output, 2004–05 (preliminary)*, cat. no. 5209.0.55.001, ABS, Canberra.

ABS 2008b, *Australian National Accounts: Tourism Satellite Account, 2006–07*, cat. no. 5249.0, ABS, Canberra.

ABS 2008c, *Electricity, Gas, Water and Waste Services, Australia, 2006–07*, cat. no. 8226.0, ABS, Canberra.

AusAID 2006, *Australia's Overseas Aid Program Budget 2006–07*, Commonwealth of Australia, Canberra.

BITRE (Bureau of Infrastructure, Transport and Regional Economics) 2008, 'Information Sheet 27: Public road-related expenditure and revenue in Australia (2008 update)', Commonwealth of Australia, Canberra.

BTE (Bureau of Transport Economics) 2001, *Economic Costs of Natural Disasters in Australia*, Report 103, BTE, Canberra.

Campbell, K., Gulledge, J., McNeill, J., Podesta, J., Ogden, P., Fuerth, L., Woolsey, J., Lennon, A., Smith, J., Weitz, R. & Mix, D. 2007, *The Age of Consequences: The foreign policy and national security implications of climate change*, Center for Strategic and International Studies, <www.csis.org/media/csis/pubs/071105_ageofconsequences.pdf>.

Cline, W.R. 2004, 'Climate Change', in B. Lomborg (ed.), *Global Crises, Global Solutions*, Cambridge University Press, pp. 13–43.

Dasgupta, P. 2007. 'Commentary: the Stern Review's economics of climate change', *National Institute Economic Review* 199: 4–7.

Gurría, A. 2008, 'Energy, environment, climate change: unlocking the potential for innovation', keynote speech by the OECD Secretary-General, during the World Energy Council: Energy Leaders Summit, London, 16 September, <www.oecd.org/document/18/0,3343,en_2649_33717_41329298_1_1_1_1,00.html>.

Hotelling, H. 1931, 'The economics of exhaustible resources', *Journal of Political Economy* 39(2): 137–75.

IPCC (Intergovernmental Panel on Climate Change) 2007, *Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor & H.L. Miller (eds), Cambridge University Press, Cambridge and New York.

Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S. & Schellnhuber, H.J. 2008, 'Tipping elements in the Earth's climate system', *Proceedings of the National Academy of Sciences of the USA* 105(6): 1786–93.

Nordhaus, W. 1994, *Managing the Global Commons: The economics of climate change*, MIT Press, Boston.

Nordhaus, W. 2008, *The Challenge of Global Warming: Economic models and environmental policy*, Yale University, New Haven, Connecticut.

Peck, S. & Wan, Y. 1996, 'Analytic Solutions of Simple greenhouse Gas Emission Models', Chapter 6 in E.C. Van Ierland & K. Gorka (eds), *Economics of Atmospheric Pollution*, Springer Verlag, New York.

Stern, N. 2007, *The Economics of Climate Change: The Stern Review*, Cambridge University Press, Cambridge.

Wainwright, E. 2005, 'How is RAMSI faring? Progress, challenges, and lessons learned', *Australian Strategic Policy Institute Insight* 14.

Weitzmann, M. 2007 'The Stern Review of the Economics of Climate Change', book review, *Journal of Economic Literature*, <www.economics.harvard.edu/faculty/weitzman/files/JELSternReport.pdf>.

Wigley, T.M.L. 2003, *MAGICC/SCENGEN 4.1: Technical Manual*, National Center for Atmospheric Research, Colorado.