9 THE MODELLED ECONOMIC CONSEQUENCES OF CLIMATE CHANGE IN AUSTRALIA

Key points

The joint Garnaut–Treasury reference case suggests that, in the absence of climate change or costs from its mitigation, from 2005 to 2100, the Australian population will more than double to nearly 47 million, per capita output will almost quadruple, and economic output will expand by over 700 per cent.

Over the same period, the reference case sees global population increasing by about 40 per cent and stabilising, and then starting to decline late in the second half of the century. Global output increases by about 15 times, mostly in the developing world, led by the large Asian developing economies—China, India and Indonesia.

The median temperature and rainfall outcomes for Australia from climate change with unmitigated growth in global emissions—particularly from impacts on infrastructure, agriculture and international terms of trade—may see GDP fall from the reference case by around 4.8 per cent, household consumption by 5.4 per cent and real wages by 7.8 per cent by 2100.

This would represent significant reduction of economic growth and welfare from what it would have been in the absence of climate change.

These are not the total costs of climate change. Nor can these costs be avoided entirely by mitigation.

This chapter draws on the scientific evidence presented in earlier chapters on the relationship between global warming, climate change and climate change impacts, to assess the economic effects of climate change on primary production, human health, infrastructure, international trade and tropical cyclones.

To understand the potential economic implications of climate change for Australia, appropriate scientific and economic frameworks must be combined to estimate impacts at the regional level. This is not a trivial task. As discussed in chapters 3 and 5, 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 climate change is a difficult, and at times speculative, task.

As a result of such uncertainty, and the complexities and limitations associated with economic modelling frameworks and assumptions over very long timeframes, the economic modelling presented in this chapter should be interpreted as indicative and broadly illustrative of the direction of change and magnitude of costs from climate change. As cautioned in the Stern Review (2007: 161), 'modelling the overall impact of climate change is a formidable challenge, demanding caution in interpreting results'. The Review reiterates this warning.

Such warnings must also be heeded when using climate change impact modelling as a basis for a cost–benefit evaluation of policy on climate change mitigation. The costs of climate change mitigation come earlier and are better known than the costs of climate change.

Chapter 2 noted that while economic modelling can provide a valuable tool to evaluate the potential economic consequences of climate change, it should not be used in isolation, or without regard to other potentially significant market and non-market impacts that are not amenable to quanitification through economic models. Chapter 10 discusses the extent of these impacts and their potential economic consequences.

In undertaking the pioneering economic analysis presented in this chapter, the Review has combined a range of expert views and modelling frameworks, some highlights of which were presented in Chapter 7. This is a first step towards a comprehensive framework for analysing the economic impacts of climate change for the Australian economy. The Review looks forward to further empirical work and refinement by others improving the estimates provided in this chapter.

The modelling presented in this chapter assesses the economic impacts of climate change as they occur under median or best-estimate[1] climate change outcomes over the current century. Impacts are estimated with consideration to their market effects on economic sectors such as agriculture, electricity and residential dwellings. The assessment precludes the assessment of non-market effects, such as the impacts of climate change on biodiversity and ecosystems and some aspects of human health. Section 6.3 and chapters 2 and 10 discuss the implications associated with excluding non-market effects from an economic evaluation of climate change.

The remainder of this chapter describes the results, assumptions and methodology underpinning the economic modelling. Detailed discussion of the full modelling results, modelling frameworks and methodologies will be provided in the supplementary draft and final reports.

9.1 Capturing the impacts of climate change through economic modelling

There are a number of types of mechanisms and models through which economic modelling of climate change could be undertaken. These include integrated assessment modelling, partial equilibrium modelling, and computable general equilibrium modelling, all of which have strengths and weaknesses.

Integrated assessment modelling incorporates socio-economic and biophysical assessments of climate change at the global and broad country level by capturing the feedback between economic and scientific systems. Such modelling usually involves broad assumptions at a high level of spatial and sectoral aggregation. The global and sectorally aggregated nature of most integrated assessment modelling makes its use inadequate for a detailed Australian industry and regional analysis.

Partial equilibrium modelling allows detailed industry specific economic evaluation. However, partial equilibrium models are not linked into the broader economy and therefore do not consider the feedback from changes in prices and opportunity costs from outside the specific industry. They are therefore inadequate when considering the economy-wide implications of climate change, but can be valuable as a complement to economy-wide modelling.

Computable general equilibrium (CGE) modelling is capable of capturing the economy-wide inter-sectoral reallocation of resources that may result from climate change. This type of modelling is useful when direct change or impacts, at either the specific industry or regional level, are expected to have economy-wide implications.

Climate change impacts will have diverse effects on a range of industries and sectors of the economy. Within this context, CGE modelling is considered the most useful and appropriate framework currently available to undertake a comprehensive assessment of the economic costs of climate change in Australia. Of these models, the Monash Multi Regional Forecasting Model, described in section 9.2.3, has advantages because of its capabilities for environmental analysis as well as its rich sectoral and regional detail.

To date, no comprehensive modelling of climate change using a CGE model has been undertaken at the Australian economy level. At the international level, there are few CGE studies that map physical effects of climate change to economic effects in a systematic or comprehensive way (see Box 9.1).

The modelling undertaken by the Review accounts for a broad range of detailed climate change impacts as they affect various sectors simultaneously over the next century. This analysis allows a dynamic assessment of a set of unmitigated and mitigated climate change scenarios, and provides regional and sectoral detail of the Australian economy. The analysis also allows for the effects of climate change internationally, and its indirect impact on Australia's international trade, by linking to a global CGE model.

Box 9.1 Modelling of climate change impacts using CGE modelling

There are few published examples of Australian studies using CGE models that examine the economic impacts of climate change. One recent study is the Australian Bureau of Agricultural and Resource Economics' assessment of the impacts of climate change on dryland broad-acre agriculture (wheat, beef, sheep meat and wool) (Heyhoe et al. 2007). This analysis considers high and low rainfall outcomes based on a given global (and local) temperature change to 2030. The assessment analyses gross regional product using the AusRegion model.

Numerous international studies have attempted to evaluate the economic effects of climate change using general equilibrium models. However, few studies have comprehensively assessed the impacts of climate change over multiple sectors simultaneously over time in a dynamic CGE framework.

Moreover, the international studies that analyse the economic effects of climate change in a regionally disaggregated way rarely identify effects on the Australian economy separately. More often, Australia is included in a regional group.

In a series of papers undertaken in association with the Fondazione ENI Enrico Mattei and Robert Roson of the Ca' Foscari University, the effects of climate change have been analysed separately for several dimensions of the global economy. These include tourism (Berrittella et al. 2006), coastal erosion (Bosello et al. 2007) and human health (Bosello et al. 2006), each of which uses a comparative static framework. The shocks applied are based on climate change impacts taken from the FUND integrated assessment model. There are no complete time paths for the global economy, either with or without climate change effects.

More recently, the Fondazione ENI Enrico Mattei has described a new dynamic version of its model (Eboli et al. 2008) that focuses on the global effects of climate change to 2050. Impacts are considered for agricultural production, energy demand, human health, sea-level rise and tourism. Climate change shocks are adapted from those previously used in static CGE models. For example, agriculture impact estimates are based on Tol (2002).

To the best of the Review's knowledge, only a handful of studies focused in detail on the impacts of climate change for single countries and for the impacts to multiple sectors over time (for example, Jorgenson et al. 2004; Carraro & Sgobbi 2008). These studies most closely reflect the approach being undertaken by the Review.

Box 9.1 Modelling of climate change impacts using CGE modelling *(continued)*

The Jorgensen study focuses on the impacts of climate change on the US economy to 2100. Impacts are considered for crop and livestock agriculture, forestry, fishing, the provision of heating and cooling, water supply, human health (mortality and morbidity) and protection of property and assets from sea level rise. The study attempts to consider uncertainties in climate change and economic outcomes by considering three levels of climate change (low, central and high) in combination with two sets of market outcomes (optimistic and pessimistic). Uncertainty in precipitation is considered by combining high temperature outcomes with lower precipitation ('high and drier') and low temperature outcomes combined with higher precipitation ('low and wetter'). The effects of climate change on agriculture were found to dominate the market impacts in the analysis.

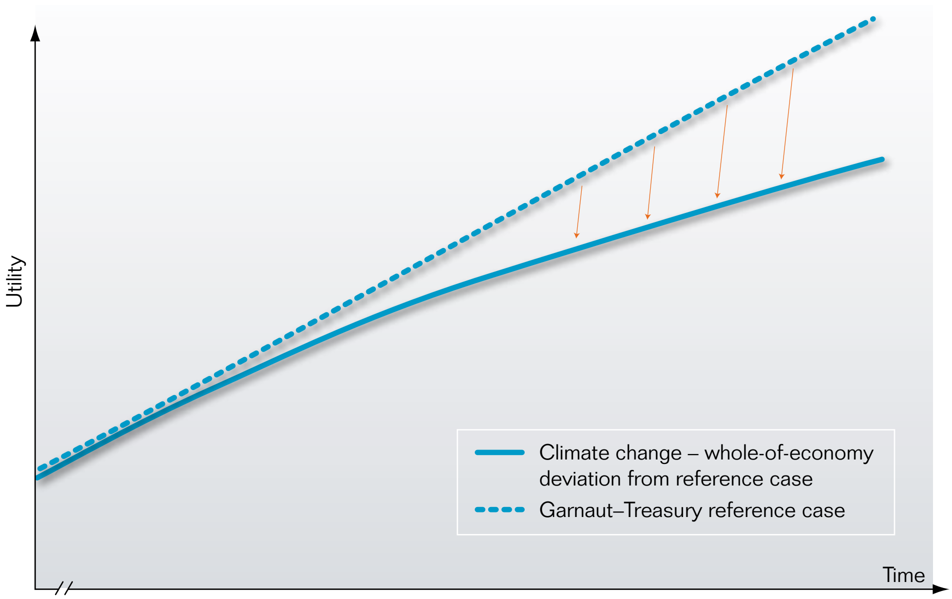
9.2 Representing climate change impacts in economy-wide analyses

The Review undertook a series of modelling tasks to illustrate the potential economic costs of climate change to the Australian economy. The first of these tasks involved the development of a hypothetical future or 'reference' case. This reference case projects the evolution of the global and Australian economies and associated greenhouse gas emissions to the end of the current century in the complete absence of climate change. The Garnaut–Treasury reference case was developed jointly by the Australian Treasury, the Centre of Policy Studies at Monash University and the Review, and drew on a wide range of external expertise. A summary of the Australian component of the reference case is provided in section 9.2.6. Chapter 4 discussed the global aspects of the reference case. Further details will be provided in the supplementary draft report.

To determine the economic consequences of climate change, various direct impacts or 'shocks' to sectors are imposed onto the reference case. These shocks cause the path of economic growth to deviate from the reference case (Figure 9.1) and represent the economic costs of climate change.

To determine these shocks, the Review worked with a range of expert groups who undertook sector-specific analyses of climate change impacts. The sectors and areas of impact considered as part of the modelling are discussed in section 9.2.2.

Figure 9.1 The costs of climate change: representing economic growth and climate change



9.2.1 Alternative scenarios to represent unmitigated and mitigated climate change

In order to determine the economic impacts of unmitigated and mitigated climate change, the Review formed a judgment about the emissions scenarios (and consequently the resulting temperature and climate changes) that may occur under unmitigated and mitigated climate change. In order to be able to begin, and complete, work on the Australian impacts of climate change within the time frames of the Review, this judgment was required well in advance of the economic analysis and modelling that underpins the reference case. The Review chose from the IPCC's *Special Report on Emissions Scenarios* (2000) the scenario that most closely reflected the Review's view of global emissions growth over the next century—the one with the highest emissions outcome, known as the A1FI—and hence the likely climate outcomes.

Section 4.5 illustrates the similarities in global emissions growth of the A1FI emissions scenario with the Review's ideas of a likely reference case emissions profile, the Garnaut–Treasury reference case. This global scenario is consistent with the reference case introduced above and discussed further in section 9.2.6, and was the basis for the no-mitigation case discussed in Chapter 5.

The choice of climate change scenarios

To determine the Australian impacts of climate change, the Review considered three median (or best-estimate) climate change outcomes: one representing an unmitigated scenario consistent with an A1FI emissions path, and two representing emissions stabilisation scenarios of 450 ppm and 550 ppm (the strong and ambitious global mitigation cases discussed in Chapter 5).

'Median' in this context refers to the median change in local average rainfall (50th percentile rainfall) and median local average temperature (50th percentile temperature) responses to a given global average temperature rise. A range of changes to climate variables is possible at the local scale—these are provided by climate models. Here we apply the likelihoods developed by the CSIRO and the Bureau of Meterology.[2] These three scenarios are represented in Table 9.1. The temperatures represented in Table 9.1 are relative to 1990 levels. As such, approximately 0.5°C should be added for these temperatures to be relative to pre-industrial times.

The results presented in this chapter relate only to the median unmitigated scenario in Table 9.1. Modelling associated with the mitigated climate change scenarios will be provided in the supplementary draft report.

Again, there are many and compounding sources of uncertainty associated with greenhouse gas emissions, global warming and climate change, and the timing and extent of impacts from each degree of warming. The cumulative nature of these uncertainties (see Figure 3.9), means that the range of possible climate change impacts on any one of the Review's choices on unmitigated and mitigated global emissions paths can be considerable.

To represent some of these uncertainties and ranges, the Review modelled an additional unmitigated scenario. All the modelled scenarios used by the Review to assess domestic impacts assume a climate sensitivity of 3°C.[3] However, uncertainty about how the Australian climate will respond to increased global average temperatures is incorporated by considering a 'dry' local rainfall sensitivity (relative to the median rainfall estimate), combined with a 'hot' local temperature sensitivity (relative to the median temperature estimate). The results for this 'hot and dry' rainfall scenario are discussed in detail in Chapter 10. The more complex climate model used to assess the international impacts has an intrinsic climate sensitivity that is somewhat less than 3.0°C.

Table 9.1 Physical climate scenarios

Scenario	Global data (2100)		Australian percentiles		Comment
	Mean temperature	CO_2 concentration (ppm)	Temperature and evaporation	Rainfall and humidity	
Unmitigated					
Median	4.5°C	976	50th	50th	Global data based on A1FI scenario using MAGICC climate model
Mitigated*					
550 ppm	2.0°C	470	50th	50th	Global stabilisation profiles created using the SIMCAP model, temperature outcomes from MAGICC
450 ppm	1.5°C	408	50th	50th	

* For the calculation of climate change impacts for the mitigated scenarios, emissions pathways and temperature outcomes were developed using the Simple Model for Climate Policy (SIMCAP) assessment, version: beta 1.0.2 (February 2006) developed by Meinshausen et al. (2006) and available at <www.simcap.org>. Climate change outcomes resulting from these emissions pathways were calculated using MAGICC version 4.1 (Wigley 2003). The local temperature and rainfall responses, by state and territory, associated with the median and dry scenarios are provided in Chapter 6.

9.2.2 Selection of key climate change impacts for use in the economic modelling

The diversity of climate change impacts on Australia makes quantifying the impacts of climate change to a level sufficient to determine economic impacts challenging and time-consuming. As a result, only a subset of impacts was included in the economic modelling exercise. This subset was selected based on the availability of data that was defined sufficiently clearly for the modelling exercise, as well as the Review's consideration of the potential scale of economic impacts on key sectors of the economy.

The key areas of impact and their subcomponents are:

Primary production		
• cropping (dryland and irrigated)	• livestock (dairy, sheep, cattle)	
Human health		
• heat stress (deaths and hospitalisations)	• vector-borne dengue viruses	• bacterial gastroenteritis
Critical infrastructure (human settlements)		
• water supply infrastructure in major cities	• electricity transmission and distribution networks	• buildings in coastal settlements
• ports operations and maintenance		
Tropical cyclones		
• impacts on residential dwellings		
International trade		

Effects on ecosystems and biodiversity; the fiscal demands on Australia that may arise from geopolitical instability in the Asia–Pacific region; effects on forestry; effects on tourism due to the reduction in environmental amenity;[4] effects on other services industries; and some effects on manufacturing[5] are among the exclusions.

Even within the key areas of impact considered, the Review was not able to capture all of the full market impacts of climate change. Due to the complexity of the modelling task, general uncertainty, and significant data limitations, it was not feasible to include all climate change impacts. For example, human health includes impacts of heat-related stress and dengue virus, but does not include the impacts of some other health issues that are likely to be affected by climate change, such as Ross River virus and mental health issues in drought-affected farming communities. As another example, the effects of increased variability and reduced predictability of rainfall may be as important for agriculture as reduced average rainfall, but these could not be taken into account.

Chapter 10 discusses the implications of excluding potentially large areas of climate change impacts from the economic analysis. It attempts to quantify the proportion of market impacts that have been captured as part of the analysis in this chapter and provides a judgment as to the size of impacts in excluded sectors.

While acknowledging the partial nature of this approach, the Review considers it a necessary and important first step in developing a deeper understanding of the costs and benefits of Australia participating in a global effort to stabilise global greenhouse gas concentrations.

9.2.3 Translating climate change impacts into economic impacts

There is currently no single model that can capture the global, national, regional and sectoral detail that was necessary for the Review's approach to modelling climate change. As a result, the Review has drawn on a number of economic models to determine the costs of climate change to the Australia economy.

The key economic model used to determine the economy-wide costs of climate change for Australia was the Monash Multi Regional Forecasting (MMRF) model (Box 9.2). The MMRF framework was supported by a series of scientific and economic models used to determine impacts in particular sectors. Detailed sector-specific modelling was undertaken for the reference case and its impact analysis. Figure 9.2 illustrates the modelling frameworks used as part of the MMRF analysis.[6]

The direct Australian impacts of climate change for both unmitigated and mitigated climate change were estimated outside the MMRF model and then incorporated as a series of shocks to economic variables in the reference case. The environmental changes likely to occur under the different climate scenarios described in section 9.2.1 were translated into direct economic impacts that could be used in the model.

Box 9.2 The Monash Multi Regional Forecasting (MMRF) model

The Monash Multi Regional Forecasting (MMRF) model is a multisector dynamic model of the Australian economy covering all states and territories. It models each region as an economy in its own right, with region-specific prices, consumers, and industries. As a dynamic model, MMRF can produce sequences of annual solutions connected by dynamic relationships.

The main features of the model include:

- Cost-minimising behaviour by firms and households—firms maximise profits and consumers maximise utility by purchasing inputs from the cheapest source; and by purchasing the bundle of goods that best meets their needs. For basic necessities, consumption is relatively insensitive to price changes. For luxuries, households substitute between goods based on their relative price.
- Substitution between factors of production—firms are assumed to minimise costs by substituting between labour, capital and land.
- Weak price-driven substitution between commodities in the production decision of firms. Firms are assumed to respond to large increases in the prices of inputs by undertaking technological innovation that reduces their reliance on the good in question.

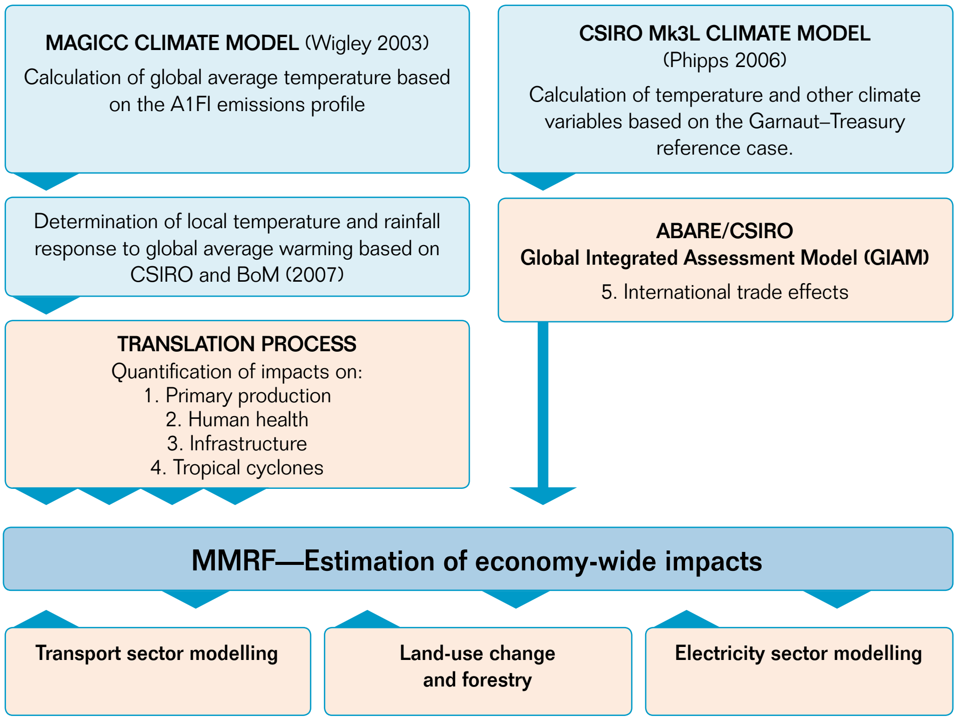
Box 9.2 The Monash Multi Regional Forecasting (MMRF) model *(continued)*

The model also includes enhanced capabilities for environmental analysis, such as:

- an energy and greenhouse gas emissions accounting module, which accounts explicitly for each of the 58 industries and eight regions recognised in the model and splits the commodity petroleum and coal products into five commodities—petrol, diesel, LPG, aviation fuel and all other coal products—produced by the petroleum and coal products industry
- model structure that allow for inter-fuel substitution in electricity generation and private road transport by region
- detailed treatment of renewable generation
- explicit modelling of the national electricity market
- special treatment of energy substitution in residential demand through the creation of energy-related service industries.

The general structure of the MMRF model is described in Adams (2007).

Figure 9.2 The Review's modelling framework



9.2.4 Dealing with adaptation

In the analysis of economic effects of climate change, a critical component is the assessment of the adaptive capacity and responses of economic agents to climate change. While ignoring such responses would overestimate the impacts of climate change, adaptation itself is not cost free.

Where the impacts avoided are non-market, adaptation will increase the market costs of climate change. For example, one of the likely adaptive responses to climate change will be to construct houses that are better able to cope with heat extremes. These modifications are likely to increase the cost of housing construction and hence increase the market costs of climate change. As a result, while market costs (construction costs) increase, non-market costs are avoided (discomfort from hot houses).

The Review has given careful consideration to the adaptive responses of economic agents for each of the key areas of impact analysed. However, quantifying such responses over very long time frames and under conditions of considerable uncertainty is a difficult task, often requiring the exercise of judgment.

The adaptive responses assumed are generally considered to occur in the absence of the introduction by government of significant adaptation policies. In some cases, however, the extension of traditional government roles into new areas has been assumed. Examples include development and enforcement of new building design standards, expenditure on public health, and participation in the breeding of new plant varieties and the dissemination of its results.

Agriculture

There are a number of adaptation responses that are inherent in the estimated direct impacts on agriculture.

For dryland cropping, it is assumed that wheat producers are able to minimise the costs of climate change by changing planting times and optimising cultivar choice. Climate change, while reducing water availability, also reduces frosts, thereby allowing planting in the wetter winter months. While it is also possible that this will reduce the planting windows for other complementary crops such as oats and barley, this possibility was not considered in the modelling.

Dairy producers are assumed to adapt to reductions in water availability by (1) switching away from irrigated and pasture fed cattle towards more intensive, grain-fed, production methods, or (2) returning to a form of dryland dairy farming (with supplementary feedstock) that was common in the first half of the last century.

Land-use change among agricultural producers is also a feature of the modelling. Scarce land resources are assumed to flow to the areas of highest return. For example, irrigation land that is no longer viable due to water scarcity can be converted to other uses, such that farmers maximise returns from land.

Infrastructure

The infrastructure analysis includes some broad assumptions regarding new planning and engineering standards to increase the resilience of buildings, port and water supply infrastructure, and electricity transmission and distribution networks.

For buildings, changes to building design (insulation and double glazing) have been included. The degree to which these standards are taken up over time depends on the replacement timelines for existing buildings and the degree of temperature changes and other climate outcomes over the period to 2100.

Expert opinion suggests that climate change will force more port closures and downtime from an increase in severe weather events. In order to cope with this change, the modelling assumes that average throughput can be maintained over time, but that larger ships and ports will be required to achieve this.

Climate change is likely to reduce the water available from traditional sources (such as dams and aquifers) for urban users. In order to cope with this change, alternative supply options, such as desalination and water recycling, have been included in the modelling. The costs and increased energy demand associated with desalination and water recycling have been included.

For electricity transmission and distribution network infrastructure, assumptions regarding investment in new capital and improved design standards have been incorporated. Examples include shifts toward below-ground transmission and distribution infrastructure to cope with an increase in severe weather events. All new greenfield urban developments are expected to be less vulnerable to severe events as a result of an immediate shift to underground distribution networks.

Health

Impacts from health are assumed to be reduced by undertaking preventive measures. While these preventive measures require government outlays, they prevent widespread outbreaks of diseases such as dengue virus and bacterial gastroenteritis.

While the Review was able to consider preventive measures, it was not able to develop an opinion on future medical advances that might further reduce the economic costs of diseases likely to be more prevalent as a result of climate change. For example, it is possible that a cure for dengue virus would reduce the time that patients take to recover, and hence reduce the time workers need to be away from their jobs.

The analysis also includes an assumption that the population will acclimatise, at least partially, to higher temperatures. This assumption builds in a limit to the range in which the human body is able to physically cope with extreme temperature. This means that temperature changes are still assumed to have some adverse impacts on the productivity of outdoor workers.

Adaptation in MMRF

As described in Box 9.2, MMRF has a number of features that allow agents in the model to adapt to economic impacts. The net effect of these features is that they reduce the costs that would otherwise be incurred by the economy as a result of the direct impacts from climate change.

For example, the economic loss from a reduction in productivity in a single industry can be minimised by agents switching purchasing decisions towards substitutes that are not as heavily affected. Where demand is relatively price insensitive, for example where a good is a required input to the production of another firm, or is a basic consumer good, firms are able to substitute between factors, or become more factor-intensive in order to meet demand. However, this adaptation comes at a cost—in this case, higher costs from the use of additional inputs.

9.2.5 Limitations to the analysis

The many and compounding sources of uncertainty associated with climate change science and impacts analysis, as well as the uncertainties inherent in undertaking economic modelling over very long time periods, mean there are significant limitations to the analysis.

Incorporating the breadth of economic impacts of climate change

The nature of the modelling undertaken by the Review does not allow for feedback of impacts from climate change in an internally consistent or integrated way. The domestic economic modelling framework is a traditional market model. It does not explicitly account for feedback from environmental changes to changes in economic factors or activity. As a result, the analysis is limited to the five key areas of climate change impact, and their economic effects, that could be determined outside the model and manually imposed as a shock.

The specified climate change impacts have been incorporated in a detailed and comprehensive way. This allows a much more robust assessment of the individual climate change impacts than would be possible using an integrated assessment model. It also illustrates and tests a methodology that can be taken further in subsequent work.

While many of the impacts of climate change have been excluded from the analysis, the Review is of the opinion it has captured a sizeable proportion of the 'median' impacts that are manifested through market processes (see Chapter 2).

Market versus non-market impacts

Non-market services are not traded in conventional markets but have considerable value to many Australians. This means that traditional market models, such as MMRF, cannot capture their effect.

For example, one of the possible impacts of climate change could be an increase in mortality. This is likely to have both market and non-market consequences. The loss of life or quality of life is a non-market impact and cannot be captured in a CGE framework. The market impacts, on the other hand, may include a reduction in the labour force, a reduction in labour productivity and/or an increase in the requirements for health services. It is these market impacts that are captured in a CGE framework.

Chapter 10 discusses the wider context of costs of climate change within which the contents of this chapter should be seen.

Treatment of uncertainty and risk

The cumulative nature of the uncertainties associated with climate change science and impacts anlaysis means that the range of possible outcomes from any one of the Review's choices on unmitigated and mitigated global emissions paths can be considerable.

Given the detailed sectoral and regional focus of the Review's economic modelling, and the modelling frameworks used, it was not possible for the Review to model climate change impacts probabilistically to account for the large range of possible outcomes.

In further development of this work, it would be desirable to undertake sensitivity analysis on each of the key areas of uncertainty, potentially with reference to higher and lower areas of the probability distributions. Given the non-integrated nature of the MMRF modelling framework, and the manual linking and estimation required for each of five key areas of impact being considered, this will be a significant task. Attempting to model the large range of outcomes for each variable in the chain of events from emissions to economic impacts would be an extraordinary task in a modelling framework such as MMRF. The number of simulations required to deal with the range of uncertainties would be immense.

In dealing with the sources of uncertainty, the Review's general approach was to choose a best-estimate for each of the decision parameters required. This best estimate was generally determined by reference to the 'middle' or central outcome of the range of possible outcomes.

For example, in relation to global average temperature change, the best estimate of 3°C climate sensitivity was used for the domestic impacts analysis. However, the temperature response may very well be higher or lower. While unlikely to be less than 1.5°C, values substantially higher than 4.5°C cannot be excluded (see Chapter 3).

The climate change response to temperature increase is also highly uncertain for a number of climate variables, as discussed in Chapter 5. For Australia, variability is particularly pronounced for rainfall. The Review has chosen to deal with the uncertainty in how the Australian climate will respond to increased global average temperatures by considering an additional 'dry' rainfall sensitivity. Results and discussion of the dry scenario are provided in Chapter 10.

These examples are only a subset of the many sources of uncertainty relating to climate change and climate change impacts. As noted above, and discussed in Chapter 3, there were many matters on which the Review was required to make decisions.

The Review is acutely aware of the limitations associated with its approach to dealing with uncertainty. It acknowledges that a best-estimate approach to the selection of key parameters will preclude analysis of low probability but high damage outcomes. It is these outcomes that are likely to pose risk of catastrophic damages from climate change and which should feature prominently in an overall assessment of the costs and benefits of climate change mitigation (see Chapter 2).

However, given the computational requirements of MMRF and the manual quantification of climate change impacts required for each of the key areas of impact, multiplied by the number of scenarios being considered, the chosen approach was the most appropriate in the time available for the Review. In addition, this approach does not preclude a detailed external assessment of the potential impacts of low probability but high impact events, and other extreme outcomes and responses, as a complement to the assessment of the economic impacts of climate change taken in this chapter.

Uncertainty in modelling over long time frames

The long time frames and large structural shifts involved in climate change analysis present considerable challenges for modelling. For example, very large productivity changes under more extreme climate scenarios, such as the dry unmitigated scenario, introduce a significant degree of uncertainty about the way the economy is likely to respond. Most economists think about changes at the margins. Economic models, on the whole, reflect this. Climate change is likely to introduce large changes to productivity in key sectors (Cline 2007) and hence result in significant changes to production technologies, prices and consumer behaviour.

Like most economic models, the assumed behavioural responses in MMRF are determined by parameters and data that have been derived from recent history. These responses will not necessarily still hold far into the future, or for change that is outside of recent experience. For this reason, the results for the latter half of the century, particularly for the more extreme climate scenario discussed in Chapter 10, should be treated with caution.

This limitation is an important one given that increased risks and potential impacts of unmitigated climate change are likely to be felt most severely in the second half of this century, and into the next, if left unmanaged.

Linking of global climate change impacts

For technical reasons, it was necessary for the Review to use different global average temperature changes for the assessment of domestic climate change impacts than for the assessment of international climate change impacts.

As shown in Table 9.1, domestic climate change impacts were derived from global average temperature changes estimated from the A1F1 global emissions profile and the MAGICC climate model. The international impacts were derived from global temperature changes estimated from the newly developed Garnaut–Treasury global emissions profile and the CSIRO Mk3L climate model (Phipps 2006). This has resulted in some differences in global average temperatures used for the domestic and global modelling exercises.[7]

These differences could not be avoided in the time frames available for the Review. As noted in section 9.2.1, in order to begin detailed work on quantifying the direct Australian impacts of climate change for the range of sectors and areas of impact considered, an assessment of global emissions from a business-as-usual reference case was required well in advance of the completion of the newly constructed Garnaut–Treasury global reference case. The requirements of the global model (GIAM) also necessitated a more complex model to provide regional analysis of temperature changes.

9.2.6 What would the Australian economy look like in the absence of climate change?

Climate change operates over very long time frames, with significant time lags between greenhouse gas emissions and resulting impacts. As a result, quantitative analysis of climate change impacts must take a long-term view.

The reference case projects the evolution of the global and Australian economy, and associated greenhouse gas emissions, to the end of the current century. This was a challenging exercise, requiring assumptions for a wide range of economic, social and environmental variables that can change in unpredictable ways. As the time frame expands, assumptions necessarily become more speculative.

The assumptions used draw on an extensive analysis of the historical structure, performance and evolution of the global and Australian economies. Future projections are based primarily on a continuation of historical trends, adjusted in the light of broadly accepted views on likely future behavioural shifts, for instance declining fertility rates and a gradual increase in consumer preferences for services as per capita incomes continue to rise.

The reference case presents a 'world without climate change', and so provides the starting point from which the impacts of climate change can be measured. The future structure of the economy is a crucial determinant of cost estimates—for example, a change to an industry that contributes 5 per cent to GDP will have a larger impact than the same proportionate change to an industry that only contributes 1 per cent.

The socio-economic storyline

Real economic output (real GDP) is determined by three components: population, participation and productivity (the '3Ps'). The pattern and rate of GDP growth is therefore a function of the assumptions regarding movements in population; changes in participation rates; and the growth of productivity. Trends in these variables differ across geographic regions and industry sectors.

The reference case describes a world of strong economic growth and continued improvement in technology and resource use efficiency. Global population peaks in the second half of the century, and the productivity gap between countries narrows, reducing regional differences in per capita income.

Over the century to 2100, global population is assumed to follow United Nations projections, increasing by about 40 per cent from 6.5 billion in 2005 to around 9.3 billion people at the end of the century (Chapter 4). The majority of this population growth occurs in south Asia, the Middle East and Central Asia, Africa and South America.

Over the same period, Australia's population is projected to more than double, rising from just over 20 million in 2005 to nearly 47 million by 2100. Population growth moderates in the second half of the century due to declining fertility rates. Queensland, Western Australia and the Northern Territory have rising shares of the national population, while South Australia, Tasmania and the Australian Capital Territory have falling national shares. Population shares for New South Wales and Victoria remain stable.

Productivity growth is the primary driver of the global economy, with per capita GDP projected to increase by more than 900 per cent over the coming century, compared to a 380 per cent increase over the 20th century (Chapter 4). Overall, the global economy is projected to be roughly 15 times larger in 2100 than in 2005.

Productivity growth rates vary across countries, reflecting their different stages of development and an expectation of conditional convergence in productivity levels. Existing differences in productivity levels narrow over the century. Developed countries all improve their productivity at around the same rate, while developing countries accelerate towards the productivity levels of developed countries. This acceleration occurs for all developing countries, but the rate of acceleration in the nearer term takes into account each country's recent growth performance.

In the near term, China continues to experience strong productivity growth. China's per capita GDP will reach 2005 US levels by mid century. By the end of the century, average Chinese productivity levels and living standards are approaching the range of developed countries, although they remain significantly below US levels in 2100.

For Australia, the combination of population, participation and productivity growth results in Australia's GDP level experiencing an increase of around 200 per cent between 2005 and 2050, and over 700 per cent increase to 2100. Australian GDP grows at an average annual rate of 2.3 per cent over the century. This comprises average growth in the labour supply of 0.8 per cent a year and aggregate labour productivity growth of 1.5 per cent per annum.

Sectoral trends in the global and Australian economy are driven by both supply- and demand-side factors.

On the supply side, industry sectors are assumed to have different rates of productivity growth. The sectoral differences assumed in the reference case are based on historical patterns, where some industries show considerably higher average growth rates than others. For instance, in Australia the communications industry is expected to grow at almost double the average rate, while productivity in service sectors such as public administration grows much more slowly. Over time the industry productivity growth assumptions are assumed to converge, reflecting uncertainty around how persistent historical differences will be over the century. Similar assumptions are made to the sectoral productivity of all countries based on their own historical patterns.

As a small open economy, Australia is strongly affected by global economic forces.

Rising per capita incomes in developing countries are expected to result in more of the world's population spending a larger share of their income on more energy-intensive goods and higher-value food. These forces will create strong demand for Australia's commodity exports and result in substantial changes in our pattern of trade with other nations.

China, India and Indonesia are our first, second and third largest export markets by 2100. The proportion of Australia's exports going to these three countries increases from 14 per cent in 2005 to more than 40 per cent in 2100.

Australia's terms of trade are expected to benefit from the pattern of global growth. Projecting movements in Australia's terms of trade is somewhat complicated due to the recent strong growth in export prices reflecting the surge in global demand for commodities. However, over the coming decade Australia's terms of trade are expected to fall as commodity producers around the world increase the supply of resources in response to the recent demand surge. Beyond 2020, Australia's terms of trade are expected to gradually improve as export prices return to an upward trend and import prices remain modest reflecting the likely pattern of global productivity growth. By the end of the century Australia's terms of trade remain below the level reached in recent years, and are around 13 per cent higher than in 2005.

Australian real household income is expected to grow more strongly than GDP over the century, reflecting the influence of the terms of trade. As Australia's per capita income rises we expect to see a continuation of the historical shift in household preferences towards services. In addition, the government services industry is expected to grow faster than average, in part due to the ageing of Australia's population.

The divergent industrial productivity trends combined with these two key demand–side influences, shifting household demand preferences and global demand for Australian exports, combine to influence industrial shares in the economy.

Services are expected to represent a growing share of the Australian economy, while the manufacturing sector continues its historical decline. Services are projected to increase by 2.5 per cent per annum over the century. Strong productivity growth in global manufacturing, combined with a rising nominal exchange rate reflecting the terms of trade, will result in a loss of competitiveness for the Australian manufacturing sector. The manufacturing sector as a whole is expected to grow by 1.1 per cent per annum over the century.

The mining sector in the near term benefits from the current surge in world demand for commodities. However, as resource constraints start to affect underlying productivity in the later half of the century, the mining sector is expected to experience more modest growth. On average over the century the mining sector is expected to grow by slightly less than aggregate GDP growth. The agricultural sector is expected to grow more slowly, at around 1.5 per cent per annum over the century, largely reflecting constraints on land.

Greenhouse gas emissions

The strong productivity and population growth story outlined above, combined with the changing structural mix of the economy, result in Australia's greenhouse gas emissions nearly doubling between 2005 and 2050, and nearly doubling again by the end of the century. Emissions are projected to grow more slowly than economic activity, resulting in a significant decline in the emissions-intensity of GDP from 0.6 kg CO_2-e/$ in 2005 to 0.3 kg CO_2-e/$ in 2100.

Emissions growth is in large part due to the combination of rising energy consumption and continued reliance on emissions-intensive fossil fuels. The largest contribution to the growth in Australia's emissions comes from the stationary energy sector: its emissions are projected to increase by 350 per cent to over 1200 Mt CO_2-e in 2100; which comprises around 60 per cent of projected national emissions. Transport emissions maintain a stable share of national emissions, at around 14 per cent, with strong growth in air transport emissions being offset by more modest growth in passenger transport emissions.

9.2.7 The economic costs of climate change: unmitigated climate change

The results presented in this section and throughout the remainder of this chapter, provide an indication of the economic consequences of climate change associated with the first category of climate change costs—measured market impacts of climate change (Chapter 2). Chapter 10 provides an assessment and some preliminary quantification of the additional three categories of costs associated with climate change: (1) unmeasured market impacts, (2) the insurance value of mitigation, and (3) non-market impacts that Australians value.

The results presented in this section are for the median scenario for climate damages discussed in section 9.2.1. These damages represent the Review's best estimate of those that would occur under a best-estimate unmitigated climate change scenario for Australia. As noted previously, the future climate changes that would result from global warming are highly uncertain. It is possible that the impact could either be much less or much worse than described in this section. The results presented in this section are generally presented as deviations from a reference case without climate change. For this reason, a 5 per cent reduction in GDP by 2100, should be interpreted as meaning that GDP is projected to be 5 per cent lower than it would otherwise have been in 2100.

Finally, caution should be used in interpreting GDP as a measure of economic welfare. Economic welfare is derived from consumption. While an important determinant of welfare, GDP is a measure of production. For this reason, household consumption[8] is the most appropriate indicator of welfare produced indicator by the modelling.

Macroeconomic implications of climate change for Australia

Under the median unmitigated scenario (Figure 9.3), by 2025, GDP is projected to decline by almost 1 per cent relative to the reference case without climate change. The direct effect of climate changes as well as expenditure on adaptation measures to minimise future impacts contribute to the reduction.

By 2050, the level of GDP is projected to fall by almost 2 per cent, relative to the reference case without climate change. By 2100, this loss reaches 4.8 per cent. This implies that economic output is projected to grow by 8.1 times compared with 8.6 times in the reference case without climate change. The loss equates to GDP being around $425 billion (2005–06 dollars) lower in the year 2100, relative to a reference case without climate change.

Real household incomes are likely to be reduced substantially by climate change. Declines in wages (and other income), coupled with higher consumer prices, work to reduce household consumption by around 5.4 per cent or $275 billion (2005–06 dollars) by 2100. This represents a loss of consumption equivalent to almost $5700 per person in 2100.

Figure 9.3 Changes to select macroeconomic variables, median unmitigated climate scenario, 2005–2100

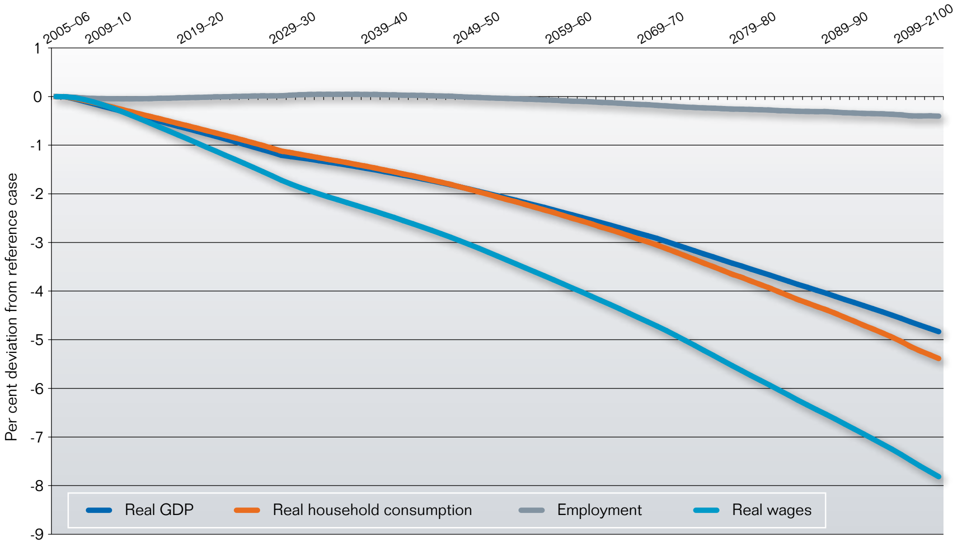


Table 9.2 shows projections for key macroeconomic variables for the median unmitigated climate scenario. It shows that the gap between the deviation in household consumption and GDP is widening through time. This is a result of the projected fall in Australia's terms of trade relative to the reference case.[9] A lower terms of trade ratio implies that a greater volume of exports are now required to pay for the same volume of imports. Household consumption is import intensive, which tends to reduce consumption levels relative to GDP.[10]

Table 9.2 Projected macroeconomic effects of climate change, median unmitigated climate scenario (per cent deviation from reference case)

Variable	2020	2050	2100
Real GDP	-0.7	-1.9	-4.8
Real gross national expenditure	-0.6	-1.9	-5.3
Real household consumption	-0.6	-1.9	-5.4
Export volumes	-0.7	-1.7	-2.0
Import volumes	-0.2	-0.8	-2.3
Terms of trade	0.1	0.1	-1.8
Real wages	-0.9	-3.0	-7.8

Changes in labour demand are captured in large changes to wages, rather than unemployment. Unmitigated climate change causes real wages to be 7.8 per cent lower than they would otherwise have been.

In interpreting these results it is important to recognise that the modelling has not been able to capture the impacts of increased climate variability. For example, although climate change is likely to result in more drought periods and an increase in the intensity of tropical cyclones, the Review is unable to predict when these events might occur. For this reason, the shocks that feed into the Review's modelling work have been averaged across time. This averaging means that the Review is unlikely to capture the short-run implications of climate-related shocks.

Short-run variability is likely to result in significant employment effects. For example, it is possible that a combination of effects could push Australia's economy into periods of recession. Unemployment is likely to increase during the recession period, and then slowly decline as the economy heads back into full employment. However, it is possible that the effects could take some time to wash through the economy. For example, recent history has shown that hysteresis effects can work to keep unemployment at high levels for reasonably long time periods. Associated effects may cause recession to lower average growth rates than have been modelled here.

Consequences for households

Climate change will have significant negative effects on households. These are likely to be differentiated across different household types. Low-income households are likely to be most negatively affected.

As shown in Table 9.2, household consumption falls by a higher proportion than GDP. As stated above, the reason for this lost purchasing power is a fall in Australia's terms of trade relative to the reference case.

At the same time, the decline in economic activity reduces the demand for labour. In order to maintain employment levels near to their long-run equilibrium, wages must fall relative to the reference case. The combined effects of lower economic growth (and hence reduced demand for labour) and higher consumer prices cause real wages to fall substantially (7.8 per cent by 2100).

The net effect of these changes is that household consumption falls by a higher proportion than GDP. Household consumption falls by 0.6, 1.9 and 5.4 per cent by 2020, 2050 and 2100 respectively, relative to a reference case without climate change.

Climate change will have disproportionate effects on food and dwelling prices. These commodities are non-discretionary goods. Lower-income families and households, who spend a high proportion of their income on these goods, are likely to be more adversely affected than others.

Climate change is likely to have adverse effects on agricultural production in Australia. Higher temperatures and especially reduced rainfall will make it increasingly difficult for Australian farms to maintain production at levels sufficient to meet foreign and domestic demand. In order to cope with water shortages, farmers require higher levels of capital and labour inputs. Additionally, increased climate variability causes farm production to become less reliable. These factors impose significant additional costs on farms and cause the cost of food to increase substantially. Relative to the general price of goods in the economy, the cost of food is projected to rise by just over 10 per cent by 2100.

Climate change will also have large impacts on the dwellings sector. The need for more stringent building codes, accelerated degradation of building materials and impacts from cyclones will impose significant costs on consumers. The modelling undertaken by the Review shows that, relative to the general price of goods in the economy, the cost of dwellings is likely to increase by more than 5 per cent by 2100.

The modelling shows that climate change is unlikely to affect all income types uniformly (Table 9.3). While wage income falls substantially, non-wage income is less affected.

Table 9.3 Changes to income types (per cent deviation from reference case)

Income type	2020	2050	2100
Income from labour	-1.0	-3.1	-7.9
Income from land	0.6	2.4	1.1
Income from capital	-0.4	-1.4	-4.8

Capital returns are less affected than wage income since capital-intensive sectors of the economy are less affected than the economy average by climate change. For example, although profits to mining fall, they fall by less than wage rates.[11]

Returns to agricultural land are also projected to be affected significantly less than real wages. Returns to agricultural land are high relative to real wages since the quantity of arable land has fallen considerably as a result of climate change. Since domestic demand for agricultural products is relatively insensitive to price movements, the shortage of land causes higher returns. In more practical terms, farmers will require high returns in order to continue farming land whose productivity is falling. While there are likely to be significant transitional costs, particularly for those farmers whose land becomes unviable, the returns to the farm sector are likely to be affected less than incomes for the general population.

Those that derive income from wages are likely to be more adversely affected, on average, than those that derive income from capital or land.

Among land holders there are likely to be clear winners and losers. For many farmers, climate change will make land unviable. However, for farmers in less marginal land, or those that are able to adapt their production methods to a world with less water, rising food prices may prove to be advantageous.

Implications for trade

International modelling using the global model (GIAM) shows that climate change will begin to have material effects on international economies from about 2050. By 2100, the economic impacts of climate change have increased substantially, with global GDP projected to fall by 7.3 per cent, relative to a reference case with no climate change.

The economic impacts on developing countries are projected to be greater than the global average. For example, India's GDP is projected to decline by 1.3 per cent by 2050 and 11.1 per cent by 2100, relative to the reference case. This is important for Australia, since Australia's reliance on developing countries for demand for its exports is projected to grow rapidly in the reference case.

Changes to terms of trade for the regions modelled in GIAM are shown in Table 9.4.

Table 9.4 Changes to terms of trade (per cent change from reference case)

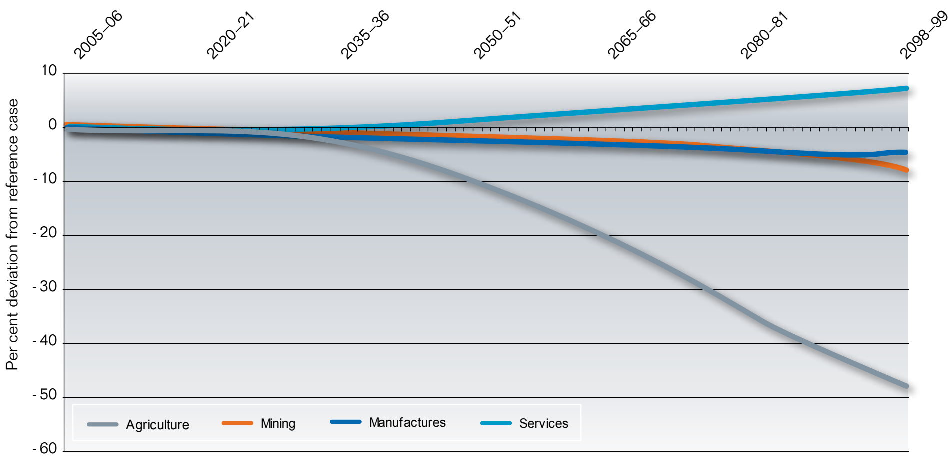
	2050	2100
United States	0.01	-0.92
European Union (25)	-0.02	-0.93
China	0.02	0.91
Former Soviet Union	-0.11	0.64
Japan	0.04	-1.35
India	0.02	0.40
Canada	-0.10	-0.58
Australia	-0.17	-2.78
Indonesia	0.05	0.84
South Africa	-0.05	-0.99
Other Asia	0.02	0.37
Rest of OPEC	-0.21	-0.14
Rest of world	0.04	0.33

The inclusion of global climate change damages affects the supply and demand for Australia's exports and imports and consequently affects Australia's terms of trade. In the global modelling undertaken by the Review, Australia's terms of trade are projected to be affected more adversely by climate change than those of any other country or region covered by the analysis. In particular, Australia's terms of trade are projected to deteriorate due to climate change impacts by about 2.8 per cent[12] at 2100, relative to the reference case.

The projected decline in Australia's terms of trade is dominated by declines in Australia's average export prices rather than changes in average import prices. In particular, as a result of climate change and the the associated changes in global production and demand for goods, Australia's average export price is projected to decline by about 3.2 per cent relative to the reference case. In contrast, Australia's average import price is projected to decline by only 0.4 per cent relative to the reference case.

The combined effect of lower trade volumes and lower prices reduces real incomes accruing to Australians from trade. The reduction in global demand, combined with the impacts of climate change on the costs of domestic production, and hence export prices, reduces export volumes of Australian commodities significantly. The projected changes in export volumes are shown in Figure 9.4. While exports of agriculture, mining and manufactured commodities are projected to decline, changes in the real exchange rates assist service exports.

Figure 9.4 Changes to export volumes, 2005–99



Industry impacts

The MMRF model produces projections for 58 industries. While this can be useful for identifying those industries likely to be disadvantaged or advantaged by climate change, some caution is required when analysing the results. Since the Review has only considered a subset of impacts in the modelling, there may be significant sectoral bias in the results. For example, the Review has not considered the likely effect that a decline in environmental amenity might have on tourism due to the difficultiy of estimating the effects of climate change on that sector. Despite this caveat, the industry results are useful in demonstrating that the impacts of climate change will not be felt evenly across the economy.

The modelling shows that output falls for almost every industry. However, some industries are particularly adversely affected. Agriculture is the most affected sector in the economy, reflecting the very large productivity losses in that sector.

As shown in Chapter 7, increased temperatures and reduced rainfall are likely to cause substantial reductions in agricultural output. However, the decline in agricultural output is substantially lower than would be implied by the productivity loss alone. Export volumes (Figure 9.4) fall by proportionately more than output, implying that domestic demand for agricultural products is relatively unaffected. Since food products are relatively price-inelastic goods, domestic demand is maintained despite significant price increases.

The mining industries are also adversely affected by climate change. Output of mining is projected to decline by more than 5 per cent, relative to the reference case, by 2100. The coal industry is by far the most affected, with output projected to decline by almost 10 per cent, relative to the reference case, by 2100. This result is mainly driven by changes in world demand, since the majority of coal produced in Australia is exported. The international modelling undertaken by the Review implies that world demand[13] for coal falls by almost 18 per cent, relative to the reference case. Iron ore activity is also projected to decline, relative to the reference case, for much the same reason as for coal.

State and territory results

As noted earlier, the Review has not considered all of the possible market impacts of climate change. For impacts that are region specific, their exclusion is likely to introduce a bias towards those states where impacts are able to be estimated most completely. For this reason, relativities between states and territories need to be interpreted cautiously.

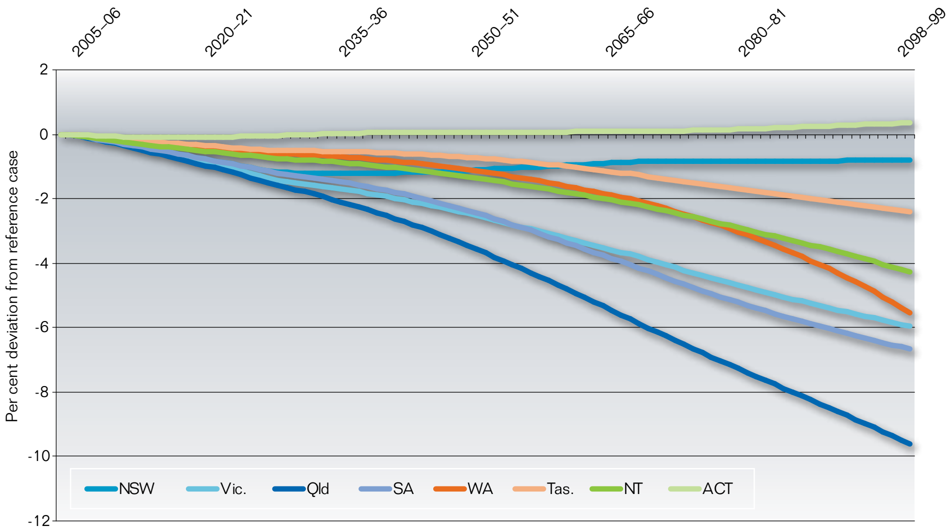
Despite this shortcoming, the Review's work highlights some key regional differences. Largely, impacts are most extreme in regions that:

- are disproportionately affected by climate change
- have a higher concentration of industries that are vulnerable to climate change, or
- have a higher proportion of industries that are vulnerable to changes in world demand.

The projected changes in gross state product (GSP) for each state and territory, relative to the reference case, are shown in Figure 9.5. The projected results of climate change differ significantly across the states and territories.

Some caution needs to be used in interpreting this chart since there are significant population changes projected in the modelling, and the GSP results are *not* presented on a per capita basis. Readers should also keep in mind that the results are presented as deviations relative to the reference case. That is, the results show that regions will grow less quickly than they would in a world with no climate change.

Figure 9.5 Projected changes to gross state product, 2005–99



Queensland is projected to be most affected by climate change for a number of reasons. Queensland has large export-orientated mining (especially coal) and agriculture sectors (primarily beef, sugar and to a lesser extent cotton). These sectors are expected to be hit hard by climate change. Global demand for coal is projected to decline sharply (world demand is projected to fall by almost 18 per cent by 2100 relative to the reference case)[15] and beef and sugar production is projected to fall significantly as rainfall declines. Reductions in economic activity and hence employment opportunities, relative to the reference case, slow the migration of people from interstate.[16]

Climate change is projected to have relatively large effects on GSP in Victoria and South Australia. In both states agriculture is expected to be hit hard by climate change. However, these regions are less affected than Queensland because the global impacts on mining commodities in these states are much lower.

Activity levels in the Northern Territory are less affected than in Victoria and South Australia since its economy is less dependent on agriculture.

Western Australia is less affected by climate change in the first half of the century, since its agricultural regions are initially unaffected. In the second half of the century, damages in Western Australia increase as climate change begins to affect its agricultural output and world demand for mining commodities begins to fall.

New South Wales is also projected to do less poorly than the average of the rest of the country in a world with climate change. There are two main reasons for this. Firstly, New South Wales is relatively intensive in services, which is the sector least affected by climate change. Secondly, agriculture in New South Wales makes only a small contribution to GSP. By 2100, agriculture contributes around 2 per cent to New South Wales' GSP compared with the economy-wide average of around 5 per cent. The relatively mild economic impact in New South Wales slows the rate of outward migration and increases the state's population relative to the reference case.

Tasmania is also relatively unaffected since climate changes are projected to be relatively small and its industries are less susceptible to climate damages. Tasmania's climate is relatively cool compared to the rest of Australia, and, unlike most other regions in Australia, it has a surplus of water resources.

The Australian Capital Territory is unaffected since its main activity is related to the running of government and the modelling assumes that government consumption is unaffected by climate change.

9.3 The contribution of individual climate change impacts to net economic impacts

This section briefly discusses each of the five key areas of impact considered as part of the economic modelling and their contribution to the net economic effects of climate change.

In order to demonstrate the relative contribution of each impact area, the Review has modelled each separately. While this provides an indication of the economic effects each impact area would have on its own, caution must be used in interpreting the results since the results are not additive.[17]

Each of the modelled impact area's effects on household consumption is summarised in Table 9.5.

Table 9.5 Projected changes to consumption from individual impact areas (per cent deviation from reference case)

	2020	2050	2100
Infrastructure	-0.53	-1.23	-2.42
Agriculture	-0.10	-0.67	-2.14
Global impacts	0.00	-0.08	-1.40
Human health	0.00	-0.02	-0.08
Cyclones	0.00	-0.01	-0.02

9.3.1 Infrastructure

The impacts of climate change on infrastructure are projected to have the most significant effects on Australia's output and consumption of goods and services. This result is perhaps not surprising, given the high value and diversity of infrastructure assets. As discussed in Chapter 7, the infrastructure impacts encompass a wide range of assets, including commercial and residential buildings, water supply and electricity infrastructure, and ports. The high value of these assets means that even marginal changes can have large economic implications.

A simple calculation can help demonstrate the economic importance of assets such as residential buildings. In 2005–06, residential buildings made up approximately 40 per cent of total Australian capital stocks. Returns to capital stocks, in the same year, contributed around 40 per cent of total income, which suggests that residential buildings alone contributed around 16 per cent to total income.

9.3.2 Agriculture

The impacts on the agricultural sector are projected to have large effects on economic welfare. A simple calculation can provide some insights as to the relative size of the economic effects of the impacts on agriculture. While agriculture contributes approximately 3 per cent to GDP today, by 2100 this has climbed to around 5 per cent under the reference case.[18] With other things fixed, a 40 per cent reduction in agricultural factor productivity would reduce GDP by around 2 per cent in 2100.

The back of the envelope method provides a reasonably close measure for the actual impacts because demand for agriculture is relatively insensitive to price changes. Rather than affect output, the loss of productivity will result in agriculture drawing more resources from the economy in order to meet this inelastic demand. We expect this result since food is an essential consumer good and climate change will most likely make food production more difficult. Producers will need to adapt to climate change and this adaptation will require significant additional resources.

In order to maintain production at levels justified by domestic and world demand and prices, agriculture will need more resources. These scarce resources will have to be drawn away from the rest of the economy.

There are a number of key assumptions and limitations which are important in determining how the direct impacts on agricultural productivity flow through as economy-wide effects.

It is assumed that domestic consumption of food products is relatively insensitive to price changes over a period in which incomes grow considerably. For example, the Review has assumed that domestic consumption of meat remains high despite significant increases in the price of meat.[19]

While the modelling undertaken by the Review shows food imports increasing, the Review has constrained the extent to which imports replace domestic food production. There are two key factors that have influenced the Review's thinking in this regard. First, growth in developing countries over the next 100 years is likely to result in increases in the cost of food produced overseas. Second, 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.

9.3.3 Terms of trade changes from global impacts

The impacts of climate change in other countries will have significant implications for economic welfare in Australia.

The global modelling (GIAM) suggests that world GDP is likely to fall by around 7 per cent by 2100, relative to a reference case with no climate change. The modelling also suggests that losses in developing countries are likely to be higher than the global average.

This is important since, by 2100, developing countries in our region are projected to become our major trading partners. As discussed in section 9.2.6, in the reference case with no climate change fast growth in these countries is projected to boost demand (and hence prices) for Australian commodities and lead to significant terms of trade gains.

Terms of trade gains boost welfare in Australia by generating foreign income which can be used to purchase imports. In the reference case, by 2100 Australia's terms of trade are projected to be around 13 per cent higher than in 2005.

Declines in global activity, particularly in developing countries, work to undo many of the gains experienced from strong global growth in the reference case.

9.3.5 Health

The health-related impacts considered by the Review have relatively small economic effects. As shown in Table 9.7, by 2100 the impacts from health cause, in isolation, a 0.08 per cent decline in consumption, relative to a reference case with no climate change.

The interpretation of these results must be considered cautiously since, as outlined in section 9.2.5, the Review has only captured a component of the likely total health impacts. Nevertheless, the results show that, providing the appropriate preventive health measures are undertaken, the impacts of climate change on human health can be managed without large economic cost. The effects of climate change on health are important for values that do not weigh in the marketplace (see Chapter 2).

9.3.6 Tropical cyclones

The impacts of tropical cyclones are also shown to have a relatively small impact on Australian consumption of goods and services. While a single cyclone event has the potential to create significant economic damage, particularly if it was to hit a population centre in south-east Queensland, these events are relatively infrequent. Taken as a series of annualised losses, the economic impacts are small.

These results however, need to be interpreted with some caution. In the time available 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. In addition, the Review was only able to capture the costs associated with damage to dwellings. There are also likely to be costs associated with damage to other infrastructure and from business disruption. This implies that the cyclone impacts captured by the Review may be underestimated.

9.4 A final caution

The fact that there are substantial costs of climate change do not make a case for any degree of mitigation. Mitigation has costs; and no degree of mitigation commenced in 2008 or 2010 will avoid all of the costs of climate change. The assessment of whether and how much mitigation is justified depends on comparisons of the costs of mitigation, with the costs of climate change that are actually avoided. For that comparison, we need the results of the economic modelling that will be reported in the supplementary draft report. It will also require assessment of a wider range of costs of climate change, as introduced in Chapter 2 and discussed further in Chapter 10.

Notes

1 Median rainfall and local temperature outcomes are assumed. See section 9.2.1 for further discussion. These outcomes have the highest likelihood of occurring based on current understanding and model outputs, but higher or lower outcomes are likely.

2 For more information see <www.climatechangeinAustralia.gov.au>.

3 In the Fourth Assessment Report, the IPCC estimates that the annual mean global surface temperature is likely to increase by between 2°C and 4.5°C following a doubling of carbon dioxide concentrations in the atmosphere—this is known as 'climate sensitivity'. The response is very unlikely to be less than 1.5°C, but values substantially higher than 4.5°C cannot be excluded. The best estimate of the IPCC is about 3°C.

4 The effects on the demand for tourism and other services from the slowing of growth and world incomes from climate change have been captured.

5 Some broad impacts to manufacturing have been captured in the modelling, such as productivity losses of workers from heat related stress as well as the impacts on trade. While the Review has excluded some impacts on manufacturing, particularly the effects climate change may have on some infrastructure assets, these are likely to be relatively minor.

6 For the electricity sector, MMA used the Strategist model; for the transport sector, the Bureau of Infrastructure, Transport and Regional Economics (BITRE) and CSIRO used the energy sector model (ESM) (http://www.csiro.au/science/EnergySectorModel.html); for land use and forestry, ABARE used its internal modelling capabilities for Australia and Lawrence Berkeley National Laboratories used its GCOMAP model to provide global estimates (Sathaye et al. 2005). International trade effects resulting from climate change were analysed using the ABARE/CSIRO Global Integrated Assessment Model (GIAM) (Gunasekera et al. 2008).

7 Using the A1FI emissions profile and MAGICC (Wigley 2003), the average global surface temperature change by 2090–99 is predicted to be around 4.3°C (4.5°C in 2100). Using the emissions profile from the newly constructed Garnaut–Treasury global reference case, and CSIRO Mk3L (Phipps 2006) the average global surface temperature change by 2090–99 is predicted to be around 3.0°C. There are two main reasons for this 1.3°C difference. The first is the difference in climate sensitivity between MAGICC and the climate model used in GIAM, CSIRO Mk3L. When forced by A1FI emissions, both models give results within the range of A1FI outcomes in the IPCC AR4 (~ +2.4 to +6.4°C in 2090–99 from a 1980–99 baseline), with the Mk3L outcomes towards the lower end of this range. Second, the climate forcing used in the A1FI MAGICC calculations involved a greater range of greenhouse gases and also included a projected decrease in aerosol concentrations over the modelling period. CSIRO Mk3L was forced only by changes in CO_2. CH_4, N_2O and changes in CFCs and aerosols were not included. Together, these amounted to a radiative forcing in the A1FI calculations that is 10 per cent higher than in the GIAM–CSIRO Mk3L calculations. (There are some small differences in the averaging periods used to calculate the changes.) Taken together, these differences mean there could be some downside conservatism in the estimates of the international impacts of climate change.

8 Consumption would normally be measured as the combined total of household and government consumption. In order to determine a single welfare measure the Review has chosen model 'closures' such that household consumption is an effective measure of both. That is, government expenditure levels are shocked such that levels are kept at their reference case levels plus additional expenditure required because of climate change. The Review has been careful to ensure that the welfare measure accounts appropriately for the additional expenditure households might incur to adapt to climate change. For example, households might be expected to incur additional expenditure in order to offset heat-related health effects. This expenditure is not welfare enhancing since it is required to bring welfare to levels they would have been at in the absence of climate change.

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

10 Another way to think of this is that the economy needs to produce and export more goods in order to purchase a given quantity of goods from foreigners. That is, we need to work harder to consume the same amount.

11 The rate of return on capital, in the long run, tends to return to equilibrium as capital stocks adjust. The level of capital stocks tends to approximate the change in output. Therefore a 5 per cent decline in output might be expected to cause an approximate 5 per cent decline in capital incomes.

12 The domestic modelling undertaken by the Review projects a slightly lower change to Australia's terms of trade. While the domestic and global modelling are linked via matching shifts in export demand schedules and import prices, it was not possible to ensure convergence between the two models since it was not possible to estimate detailed sectoral-level impacts for countries other than Australia.

13 Caution needs to be exercised in interpreting changes to world demand. An 18 per cent decline implies that, with prices fixed, exports will decline by 18 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.

14 A full description of projections for regional changes to precipitation can be found in Chapter 6.

15 The change in world demand is a combination of the effect of both world prices and volume demanded. An 18 per cent decline in world demand implies volumes would fall by 18 if Australian prices were fixed. However, prices are not fixed and hence volumes would not fall by 18 per cent.

16 In the reference case Queensland is projected to be a net beneficiary from interstate migration, with population projected to grow by almost 200 per cent, which is significantly greater than the national average of around 125 per cent.

17 Individual impacts are not additive because in a whole-of-economy model like MMRF, individual sectors interact with each other. Impacts on one sector will affect others. This complex interaction means that multiple impacts are likely to compound or offset each other.

18 In the reference case, growing demand for agriculture, rising international food prices and limits on the physical quantities of agricultural land mean that returns agriculture increase relative to today.

19 One factor influencing the Review's thinking on this issue is that incomes increase many times over in the reference case. While climate change will reduce incomes relative to the reference case, in 2100 they are still many times greater than they are today. In the reference case the share of income spent on food is significantly lower than it is today.

References

Adams, P.D. 2007, 'Insurance against catastrophic climate change: how much will an emissions trading scheme cost Australia?' *The Australian Economic Review* 40(4): 432–52.

Berritella, M., Biganoa, A., Roson R. & Tol, R.S.J. 2006, 'A general equilibrium analysis of climate change impacts on tourism', *Tourism Management* 27: 913–24.

Bosello, F., Roson, R. & Tol, R.S.J. 2006, 'Economy wide estimates of the implications of climate change: human health', *Ecological Economics* 58: 579–91.

Bosello, F., Roson, R. & Tol, R.S.J. 2007, 'Economy wide estimates of the implications of climate change: Sea level rise', *Environmental and Resource Economics* 37: 549–71.

Carraro, C. & Sgobbi, A. 2008, 'Climate change impacts and adaptation strategies in Italy. An economic assessment', FEEM Nota di Lavoro 6.

Cline, W. 2007, *Global Warming and Agriculture: Impact estimates by country*, Center for Global Development & Peterson Institute for International Economics, Washington DC, <www.cgdev.org/content/publications/detail/14090#Chpt>.

CSIRO (Commonwealth Scientific and Industrial Research Organisation) & BoM (Bureau of Meteorology) 2007, *Climate Change in Australia: Technical report 2007*, CSIRO, Melbourne.

Eboli, F., Parrado, R. & Roson, R. 2008, 'Climate change feedback on economic growth: exploration with a dynamic general equilibrium model', paper presented at the Eleventh Annual Conference on Global Economic Analysis, Helsinki, June, available at <www.gtap.agecon.purdue.edu/>.

Gunasekera, D., Ford, M., Heyhoe, E., Gurney, A., Ahammad, H., Phipps, S., Harman, I., Finnigan, J. & Brede, M. 2008, 'Global integrated assessment model: a new analytical tool for assessing climate change risks and policies', *Australian Commodities* 15(1): 195–216.

Heyhoe, E., Kim, Y., Kokic, P., Levantis, C., Ahammad, H. & Schneider, K. 2007, 'Adapting to climate change', *Australian Commodities* 14(1): 167–78.

IPCC (Intergovernmental Panel on Climate Change) 2000, *Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*, N. Nakicenovic & R. Swart (eds), Cambridge University Press, Cambridge.

Jorgenson, D.W., Goettle, R.J., Hurd, B.H. & Smith, J.B. 2004, *US Market Consequences of Global Climate Change*, Pew Center on Global Climate Change, Arlington, Virginia.

Meinshausen, M., Hare, B., Wigley, T.M.L., van Vuuren, D., den Elzen, M. & Swart, R. 2006, 'Multi-gas emissions pathways to meet climate targets', *Climatic Change* 75: 151–94.

Sathaye, J., Makundi, W., Dale, L., Chan, P. & Andrasko, K. 2005, 'GHG mitigation potential, costs and benefits in global forests: a dynamic partial equilibrium approach', *The Energy Journal*, Multi-Greenhouse Gas Mitigation and Climate Policy, Special Issue #3.

Phipps, S.J. 2006, *The CSIRO Mk3L Climate System Model: Technical report 3*, Antarctic Climate & Ecosystems Cooperative Research Centre, Hobart.

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

Tol, R.S.J. 2002, 'Estimates of the damage costs of climate change', *Environmental and Resource Economics* 21: 47–73.

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