ECONOMIC MODELLING TECHNICAL PAPER 1

INTRODUCTION AND OVERVIEW OF APPROACH TO ECONOMIC MODELLING

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Garnaut
CLIMATE CHANGE
REVIEW

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This is the first in a series of Technical Papers of the Garnaut Climate Change Review's discussion of the methodology and results of Modelling of the Net Costs of Climate Change Mitigation. Other Papers in the series, available on the Review's website www.garnautreview.org.au are as follows:

Technical Paper Number 1: Overview and approach to the economic modelling

Technical Paper Number 2: Climate data, methodology and assumptions

Technical Paper Number 3: Assumptions and Data Sources

Technical Paper Number 4: Methodology for modelling climate change impacts

Technical Paper Number 5: Modelling the costs of unmitigated climate change

Technical Paper Number 6: Global Climate Change Mitigation: Implications for Australia

Technical Paper Number 7: The net costs of global mitigation for Australia

1 Introduction

The Garnaut Climate Change Review (the Review) undertook economic modelling to assess the economic impacts of climate change and its mitigation on the Australian economy. To do this, a range of scientific and economic frameworks were combined to estimate impacts at the regional level.

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 economic modelling. These ‘unmodelled’ effects of climate change feature prominently in the Review’s evaluation of the costs and benefits of climate change mitigation (see Chapters 1 and 11 of the Review’s Final Report).

In undertaking the economic modelling, the Review has combined a range of expert views and modelling frameworks. 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 of the work presented by the Review.

This paper provides an overview of the approach the Review has undertaken to model the impacts of climate change as well as the costs and benefits of climate change mitigation. It is the first in a set of papers put together covering the major assumptions and results that have contributed to the Review’s modelling. The papers are intended to provide a detailed treatment of the major assumptions and results of the Review’s modelling. Further documentation of the modelling and assumptions for the costs of mitigation for Australia will be available as part of the Commonwealth Government’s modelling to be released by the end of October 2008.

The Technical Papers are structured as follows:

Paper 1: **Introduction and overview of the Review’s approach to the modelling**

Paper 2: Climate Data Methodology and Assumptions

Paper 3: Modelling Assumptions and Data Sources

Paper 4: Methodology for modelling climate change impacts

Paper 5: Modelling the costs of unmitigated climate change

Paper 6: Global Climate Change Mitigation: Implications for Australia

Paper 7: The net costs of mitigation in Australia

2 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 and its mitigation 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 and its mitigation, 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 market costs of climate change and its mitigation in Australia. Of these models, the Monash Multi Regional Forecasting Model has advantages because of its capabilities for environmental analysis as well as its rich sectoral and regional detail.

Before the Review, no comprehensive modelling of the economic impacts of climate change using a CGE model had been undertaken at the Australian economy level. This is in contrast to the significant amount of modelling that has been undertaken on the economic impacts of mitigation. 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 1.1).

Box 1.1 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.

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 scenarios, and provides regional and sectoral detail of the Australian economy. The analysis also allows for the effects of climate change and its mitigation internationally, and its indirect impact on Australia's international trade, by linking to a global CGE model.

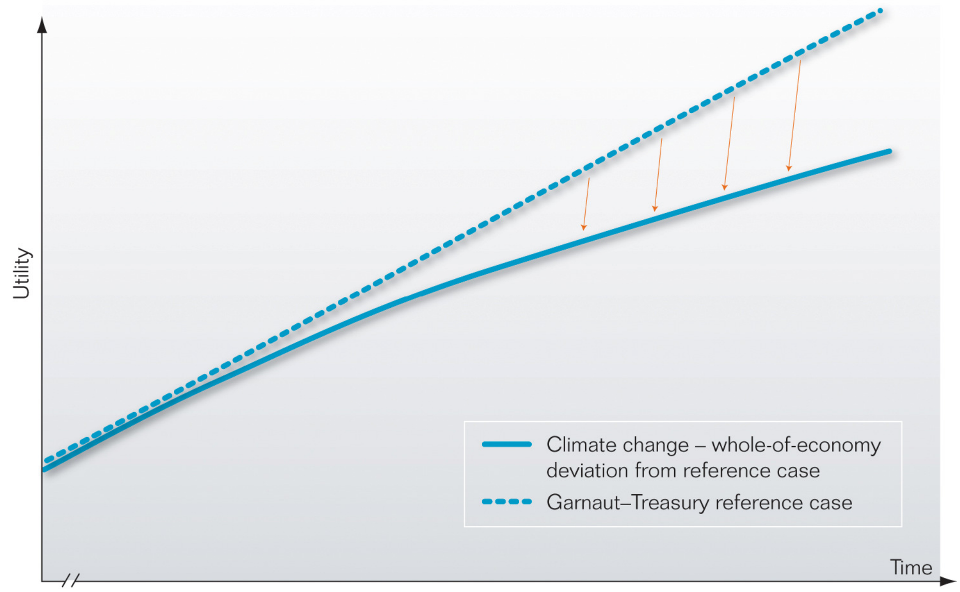
3 Representing climate change impacts in economy-wide analyses

The Review undertook a series of modelling tasks to analyse the potential economic costs of climate change and its mitigation 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 Technical Paper number 5. Chapter 3 of the Review's Final Report discusses the global aspects of the reference case.

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 1.1) 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 5.

Figure 1.1 The costs of climate change: representing economic growth and climate change



The approach represented in Figure 1.1 conceptualises how the economic effects of unmitigated climate change have been determined. The next step in the modelling was to determine the costs and benefits of mitigation for Australia.

The 'gross costs' of mitigation were modelled by the Australian Treasury and the Review and do not take into account the effects of climate change this mitigation avoids.

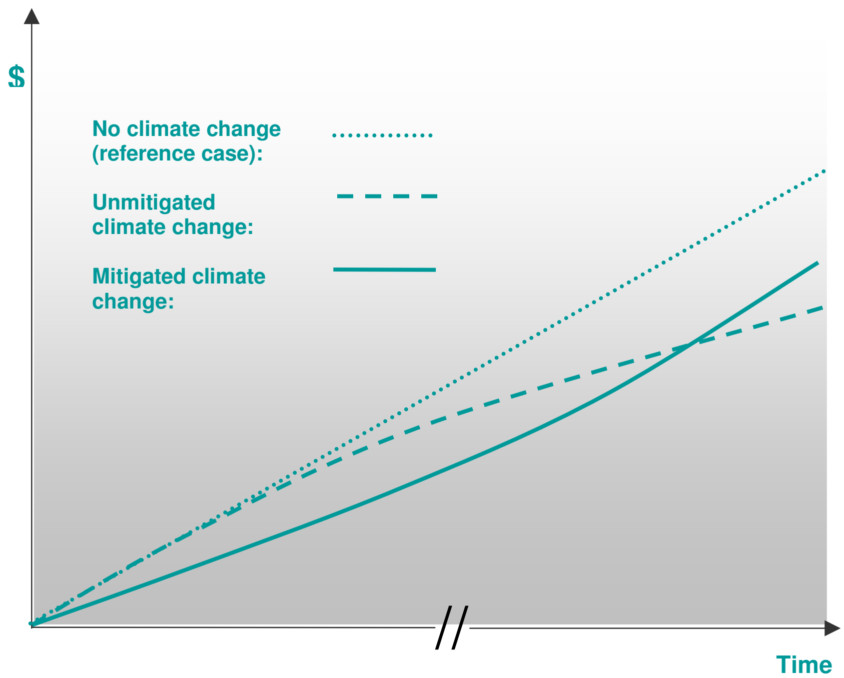
The Review's main approach to the modelling of climate change mitigation is to analyse the 'net costs' (costs of mitigation minus modelled benefits of mitigation) to Australia playing a proportionate part in a global effort to mitigate climate change. This approach is different to approaches taken in the past, including that taken by the Stern Review (2007), which measured the costs of action on climate change against the costs of inaction on climate change. To determine the economic consequences of mitigation, the reference case *with climate change* is used as the reference point from which the economic effects of mitigation are measured. This is referred to as the "no-mitigation scenario"

The no-mitigation scenario is represented as the solid blue line in Figure 1.1. By measuring the costs of mitigation against this line, the avoided impacts of climate change (the benefits of mitigation) can be determined. This analysis incorporates the lower levels of climate change and adaptation that will occur even with climate change mitigation, as well as the costs of policy introduced to reach a specified stabilisation level. This is stylised as the solid blue line in Figure 1.2 below.

In essence this growth path represents the costs of introducing mitigation policy as well as the benefits from reducing the economic impacts associated with climate change in the future. The economic modelling of stabilisation assumes that the rest of the world is 'acting-in-kind' (since domestic mitigative action alone would have a very limited effect on global warming). The domestic and global mitigation assumptions used as part of this modelling are discussed in Technical Paper numbers 6 and 7.

The Review's approach to considering the costs and benefits of mitigation accounts for four types of costs of climate change (benefits from its avoidance). The first type of costs are the expected market costs under median expectations of climate change that can be measured sufficiently robustly to be put through a general equilibrium model. The second type of costs are those that in theory are measurable but could not be measured in the time available to the Review due to data or measurement issues. The third type of costs are those associated with the more extreme end of the probability distribution. The fourth relates to the non-market effects of climate change that Australian's value. Only the first two types of costs have been considered in a comprehensive way by the Review.

Figure 1.2: The net costs of climate change mitigation



4 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. 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 carbon dioxide equivalent (CO_2-e). In addition to the median unmitigated scenario the Review considered a more severe drying scenario to capture some of the uncertainties in how the Australian climate will respond to global average temperature increases. These scenarios are represented in Table 1.1 and are discussed in detail in Technical Paper number 2.

In order to be able to begin, and complete, work on the Australian impacts of climate change within the time frames of the Review, judgment about the likely emissions paths and consequential temperature outcomes was required well in advance of the economic analysis and modelling that underpins the reference case and global mitigation scenarios. 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 in the absence of mitigation—the one with the highest emissions outcome, known as the A1FI—and hence the likely climate outcomes. For the mitigation scenarios, emissions pathways and temperature outcomes were developed using the Simple Model for Climate Policy (SIMCAP). The methodology and results of each of the unmitigated and mitigated scenarios are discussed in detail in Technical Paper number 2.

Section 3.5 of the Review's Report 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.

The temperatures represented in Table 1.1 are relative to 1990 levels. As such, approximately 0.5ºC should be added for these temperatures to be relative to pre-industrial times.

Table 1.1 Modelled climate change scenarios

Scenario	Global data (2100)		Australian percentiles		Comment
	Mean temperature	CO_2 concentration (ppm)	Temperature and evaporation	Rainfall and humidity	
Unmitigated					
Median	4.5ºC	976	50th	50th	Global data based on A1FI scenario using MAGICC climate model
Dry	4.5ºC	976	90th	10th	
Mitigated*					
550 ppm	2.0ºC	470	50th	50th	Global stabilisation profiles created using the SIMCAP model, temperature outcomes from MAGICC
450 ppm	1.5ºC	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).

5 Selection of 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, beef 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.

The project teams that assisted with this analysis are shown in Table 1.2. Each of these teams provided the Review with a detailed report on the methodology and results of the analysis of the climate impacts. These reports are available on the Review's website www.garnautreview.org.au under 'reports commissioned by the Garnaut Climate Change Review' at

http://www.garnautreview.org.au/CA25734E0016A131/pages/all-reports--resources-commissioned-reports

Details on how these impacts were translated into economic 'shocks' to be used as part of the general equilibrium model of the Australian economy (MMRF) are discussed in detail in Technical Paper number 4.

Table 1.2 Project teams for the economic analysis on selected sectors of the economy

Sector	Lead authors
Irrigated agriculture in the Murray-Darling Basin	Risk and Sustainable Management Group, School of Economics, University of Queensland
Dryland cropping	CSIRO Sustainable Ecosystems
Livestock carrying capacity	Queensland Climate Change Centre of Excellence CSIRO Sustainable Ecosystems
Buildings in coastal settlements	Maunsell Australia Pty Ltd CSIRO Sustainable Ecosystems
Urban water supply	Maunsell Australia Pty Ltd
Electricity transmission and distribution network	Maunsell Australia Pty Ltd
Port operations	Maunsell Australia Pty Ltd
Cyclone impacts on dwellings	GeoScience Australia
Temperature-related death and serious illness	National Centre for Epidemiology & Population Health School of Medicine, University of Western Sydney
Dengue virus	National Centre for Epidemiology & Population Health School of Medicine, University of Western Sydney
Bacterial gastroenteritis	National Centre for Epidemiology & Population Health School of Medicine, University of Western Sydney
Changes in export demand and terms of trade	Australian Bureau of Agricultural and Resource Economics and CSIRO

Within the selected areas of impact considered, the Review was not able to capture 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 in the modelling. 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.

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. Technical Paper number 5 discusses the Review's approach to estimating the economic effects of climate change on some of these areas outside the general equilibrium framework.

6 Translating climate change impacts into economic impacts

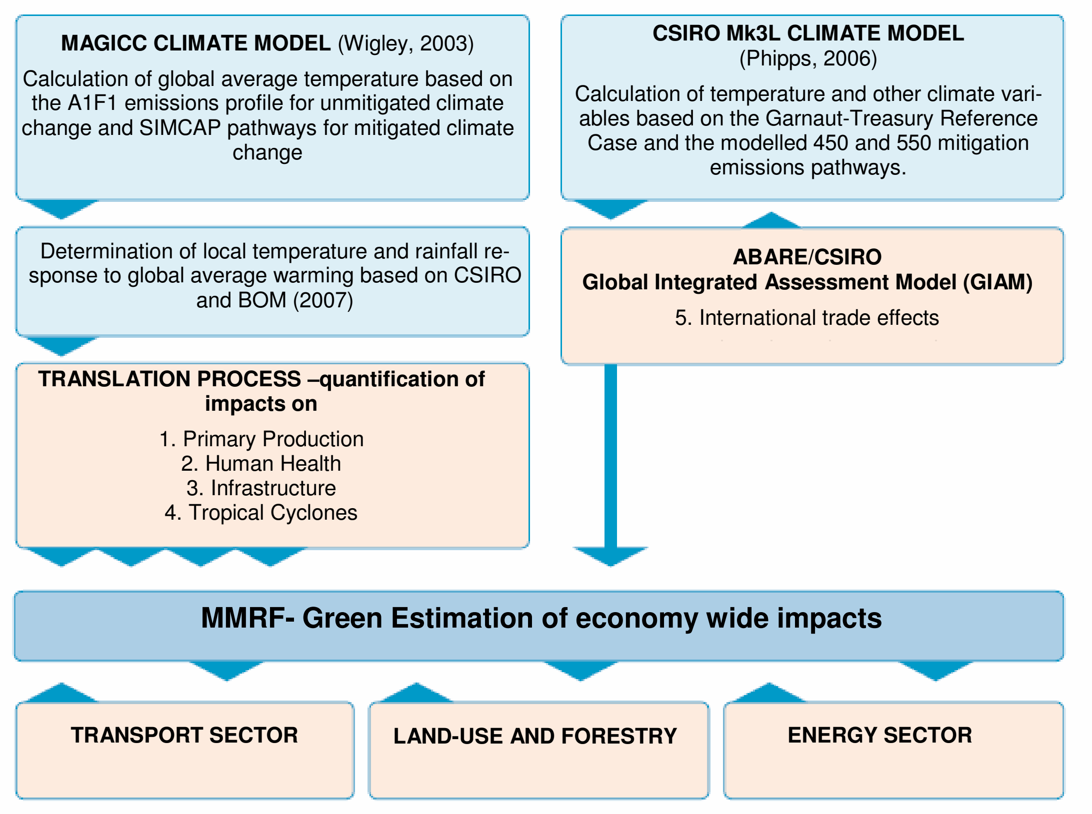
There is currently no single model that can capture the global, national, regional and sectoral detail that was necessary for the Review's approach to modelling climate change. As a result, the Review has drawn on a number of economic models to determine the costs of climate change to the Australia economy.

The main economic model used to determine the economy-wide costs of climate change and the net costs of climate change mitigation for Australia was the Monash Multi Regional Forecasting Model (MMRF). MMRF is a computable general equilibrium model of the Australia economy capable of capturing the economy wide effects of climate change and mitigation policy. The global modelling framework used to provide the international trade effects of climate change for Australia is the Global Integrated Assessment Model (GIAM). The economic module of the GIAM is the Global Trade and Environment Model (GTEM). 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 the mitigation policy modelling. Figure 1.3 illustrates the modelling frameworks used as part of the MMRF analysis.[1]

The global trade and environmental model – GTEM (the economic module within the GIAM framework) was also used to derive mitigation costs for Australia, but unlike MMRF, without the calculation of avoided climate change from mitigation.

1 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).

Figure 1.3 The Review's framework for modelling the net costs of climate change.



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 4 were translated into direct economic impacts that could be used in the model. Technical Paper number 4 discusses how these shocks were developed.

Box 1.2 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.

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).

7 Mitigation assumptions

The modelling of the two mitigation scenarios is based on costs associated with Australia adhering to an emissions allocation, derived from an international agreement, commencing in 2013, to limit the concentration of greenhouse gases to, respectively, 450 and 550 ppm CO_2-e.

The assumptions underlying the global cooperative arrangement assumed in the modelling are discussed in detail in Technical Paper number 6. The key features of this arrangement include:

- Cooperative global action from 2013 where all countries take on emissions targets covering all sectors of the economy, including agriculture and forestry.
- Emissions allocation rights determined by the Review's modified contraction and convergence and allocation assumptions where all countries converge from current emissions to equal per-capita emissions rights over time.
- Unlimited trading of emissions rights between countries and across time.

The particular features of Australia's mitigation policy within the globally coordinated mitigation effort are discussed further in Technical Paper number 7 with the key features outline below.

- Full coverage of sectors within the economy from 2013
- Permits auctioned with revenue distributed back to households as a lump sum transfer.
- No assistance to trade exposed emissions intensive industries as all countries are assumed to be taking on agreed emissions constraints based on the Review's contraction and convergence rules.

The global cooperative arrangement assumed for the purposes of modelling is a stylised post Kyoto optimal arrangement

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. To capture some of the uncertainties in the modelling of technology far into the future the Review has modelled three main technology scenarios, a 'standard', 'enhanced' and 'backstop' technology scenario. The standard and enhanced technology scenarios were modelled with the Australian Treasury as part of the joint modelling exercise of the gross costs of mitigation (within MMRF and GTEM respectively). The Review independently modelled the backstop technology scenario in MMRF. Further details of the assumptions in these technology scenarios is provided in Technical Paper number 7. A summary of the other major assumptions used in the modelling with the Australian Treasury are provided in Technical Paper number 3. This includes a discussion of, technology costs, marginal abatement costs curves and fuel prices.

8 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 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. Further discussion of some of the adaptive assumptions assumed in the modelling are available in Technical Paper number 5 and in each of the papers provide by the project teams work outlined in Table 1.2. These reports are available at www.garnautreview.org.au

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 1.2, 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 Modelling limitations

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 various limitations to the analysis undertaken by the Review.

Incorporating the breadth of economic impacts of climate change

The domestic economic modelling framework (MMRF) does not explicitly account for feedback from environmental changes to changes in economic factors or activity. As a result, the analysis is limited to economic impacts of climate change that could be determined outside the model and manually imposed as a shock to a particular economic variable.

As noted in Section 5, the modelling was restricted to five areas of climate change impact. While these impacts are considered to represent a sizeable proportion of the overall impacts, there are many exclusions. These exclusions are discussed further in Technical Paper number 5.

Despite this limitation, it is important to recognise that of the climate change impacts that have been incorporated, each have been done so 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.

Market versus non-market impacts

MMRF is not suitable for capturing the non-market impacts of climate change. Non-market services and values 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 adequately 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 only these market impacts that are able to be captured in a CGE framework

Treatment of uncertainty and risk

The cumulative nature of the uncertainties associated with climate change science and impacts analysis 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 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 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 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.

The climate change response to temperature increase is also highly uncertain for a number of climate variables. For Australia, variability is particularly pronounced for rainfall. Technical Paper number 5 reports on results based on a 'hot' and 'dry' rainfall sensitivity.

The Review is 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 feature prominently in an overall assessment of the costs and benefits of climate change mitigation (see Chapters 1 and 11 of the Final Report).

However, given the computational requirements of MMRF and the manual quantification of climate change impacts required for each of the 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. 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 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 step changes that are outside of recent experience. For this reason, the results for the latter half of the century, particularly for the more extreme climate scenario, 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.

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 1.1, 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. These issues are discussed further in Technical Paper number 2.

These differences could not be avoided in the time frames available for the Review. 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 and mitigation pathways was required well in advance of the completion of the newly constructed Garnaut–Treasury global reference case and the global mitigation modelling. The requirements of the global model (GIAM) also necessitated a more complex model to provide regional analysis of temperature changes.

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.