

ECONOMIC MODELLING TECHNICAL PAPER 5

MODELLING THE COST OF
UNMITIGATED CLIMATE CHANGE

OCTOBER 2008



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This is the fifth 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

This paper draws on the scientific evidence presented in the Review's Final Report on the relationship between global warming, climate change and climate change impacts, to model the economic effects of climate change in Australia.

The Review's assessment of the costs of climate change (and the associated benefits of climate change mitigation) is being approached through the decision framework presented in Chapter 1 of the Final Report and are informed by the modelling undertaken jointly with the Australian Treasury and independently by the Review¹. This framework takes into account four types of costs of climate change, several of which are in their nature difficult or impossible to model.

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

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

The third type of cost (Type 3) is that associated with the chance that the impacts through market processes turn out to be substantially more severe than suggested in the median cases. These derive their importance from the normal human aversion to risk in relation to severe outcomes, and from the possibility that the bad end of the probability distribution includes outcomes that are extremely damaging and in some cases catastrophic.

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

The modelling of the effects of climate change ends in 2100. The long time frames and large structural shifts involved in climate change analysis present considerable challenges for modelling the way the economy is likely to respond. Like most economic models, the assumed behavioural responses in models like that used by the Review are determined by parameters and data that have been derived from recent history. Beyond the second half of this century, the assumptions that must be made about economic parameters and relationships become highly speculative. And yet all of the detailed assessments of the economics of climate change indicate that the main costs, and therefore the main benefits of mitigation, accrue in the 22nd and 23rd centuries and beyond (Stern 2006; Nordhaus 2008; Cline 2004). Consideration of these long term costs and benefits must be a feature of any evaluation of

¹ The modelling framework used to determine the costs of climate change is 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 net benefits of climate change mitigation policy.

This paper focuses on the Review's modelling of the Type 1 costs of climate change. The aim of this paper is to provide more detail on the modelling results for the no-mitigation scenario summarised in Chapter 11. This modelling forms part of the analysis presented in Chapter 11 of the Final Report. This paper does not repeat the broader analysis of Chapter 11, which considers all four types of climate change costs, but focuses only on the details of the modelling.

2 The modeled market effects of climate change

This section presents the results of the Review's modelling of the market effects of climate change under median expectations of climate change in Australia². The results presented in this section are generally presented as deviations from a hypothetical future or '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. It does not imply the GDP would be lower than today's levels. A summary of the results of the reference case without climate change are discussed below. Further details on the reference case will be released as part of the Australian Treasury modelling at the end of October 2008.

2.1 The reference case of no climate change

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

² For technical reasons it was necessary for the Review to use different global average temperature changes for the assessment of domestic impacts than for the assessment of international climate change impacts. These differences could not be avoided in the time available to the Review. These differences are discussed further in Technical Paper Number 2.

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 940 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 750 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 37 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 are projected to be around the level of 2005, which is below the level reached in 2008, but above the levels in the last quarter of the twentieth century.

Australian real household income grows with GDP over the century. 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 growth is largely driven by strong growth in demand for communications, and financial and business services. Overall, services are assumed to increase by 2.5 per cent per annum over the century.

In contrast, the historical decline of the manufacturing sector is projected to continue. This decline is largely driven by strong productivity growth in global manufacturing, particularly in developing countries, combined with a rising nominal exchange rate reflecting the terms of trade, which results in a loss of competitiveness for the Australian manufacturing sector. Overall the manufacturing sector is assumed to grow by 1.1 per cent per annum over the century. The contraction in manufacturing's share of the Australian economy is widespread across the sector, with metal manufacturing industries such as steel and aluminium, textile, clothing and footwear, chemical manufacturing and rubber and plastics industries all experiencing annual growth lower than the national average.

In the near term the mining sector 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 grow by only slightly more than the national average, largely driven by strong growth in coal, iron ore and other metal ores. Overall the mining sector is assumed to grow at around 2.4 per cent per annum over the century.

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 CO₂-e/\$ in 2005 to 0.23 kg CO₂-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 270 per cent to over 1000 Mt CO₂-e in 2100; which comprises around 50 per cent of projected national emissions. Transport emissions maintain a stable share of national emissions, at around 15 per cent, with strong growth in air transport emissions being offset by more modest growth in passenger transport emissions.

2.2 The economic impacts of unmitigated climate change for Australia

The Review's analysis of the economic impacts of climate change for Australia, presented in Chapter 11 of the Final Report are determined based on the modelled Type 1 costs of climate change adjusted to incorporate the Type 2 costs of climate change analysed outside the CGE framework. As discussed in Chapter 11, the Type 2 costs of climate change are estimated to be 30 per cent the size of the Type 1 costs of climate change.

Using the modelling presented in figure 1.1 and Table 1.2 below, and the assessment of the Type 2 costs of climate change, the effects of climate change by the end of the century amount to approximately 10 per cent of GNP and consumption and 8 per cent of GDP, relative to the reference case of no climate change.

The results in Figure 1.1 are presented as 'costs' (positive percentage deviations) relative to the reference case with no climate change.

Climate changes as well as expenditure on adaptation measures to minimise impacts are expected to reduce GDP by 1 per cent by 2025, 2.1 per cent by 2050, and 5.9 per cent by 2100 (Type 1 costs only). This implies that economic output in 2100 is projected to be 8.1 times larger than today compared with 8.6 times in the reference case.

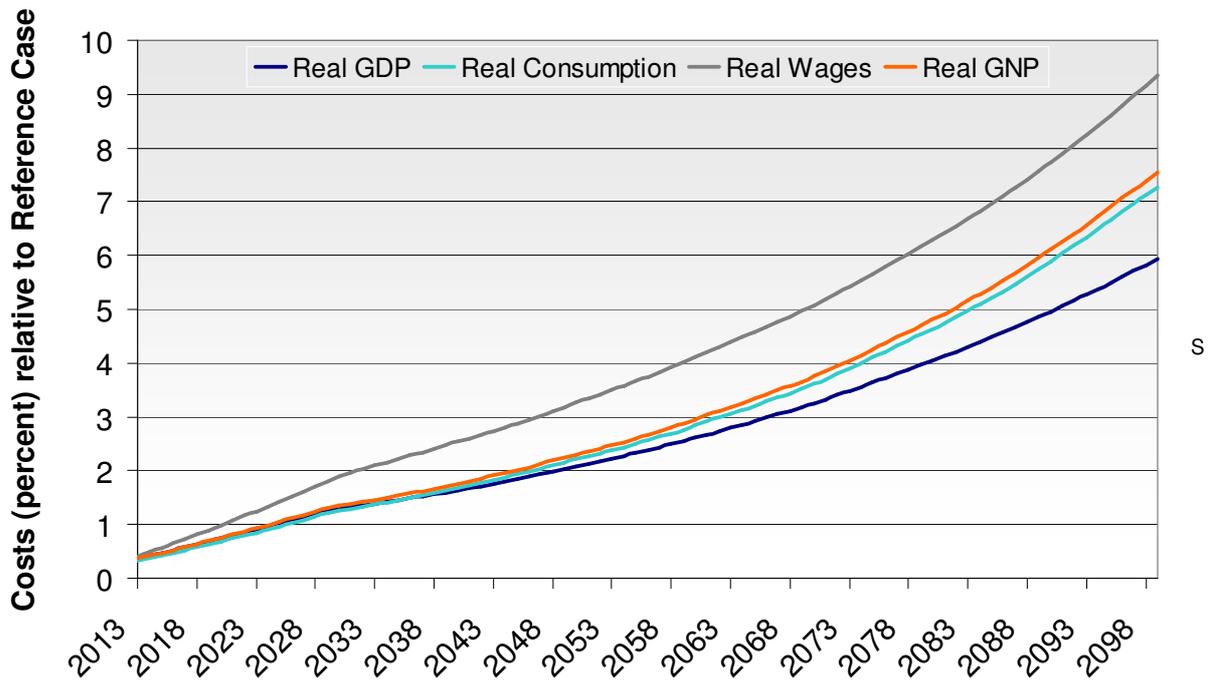
Real household incomes are likely to be reduced substantially by climate change. Declines in wages (and other income), coupled with higher consumer prices, work to reduce household consumption by around 7.3 per cent and GNP by around 7.5 per cent.

Household consumption and GDP diverge through time due to the projected fall in Australia's terms of trade relative to the reference case¹. 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 and GNP levels relative to GDP².

Changes in labour demand are captured in large changes to wages, rather than unemployment as the wage rate moves to eliminate any short run employment effects from climate change. Unmitigated climate change causes real wages to be 9.4 per cent lower than they would otherwise have been. The fall in real wages increases significantly in the second half of the century as national employment deviates from its long run rate in response to reduced demand for labour from climate change.

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.

Figure 1.1 Changes to select macroeconomic variables, median, unmitigated scenario, 2005-2100. Type 1 costs of climate change only.



Source: MMRF

Table 1.2 Projected macroeconomic effects of climate change, median unmitigated climate scenario, costs (per cent) relative to reference case – Type 1 costs of climate change only.

Variable	2020	2050	2100
Real GDP	0.7	2.1	5.9
Real GNP	0.8	2.3	7.6
Real consumption	0.7	2.2	7.3
Terms of trade	0.1	0.3	4.6
Real wages	1.0	3.3	9.4

Source: MMRF

Consequences for households

Climate change will have significant negative and differentiated effects on households with low-income households the most negatively affected.

The decline in economic activity reduces the demand for labour which, combined with higher consumer prices, causes real wages to fall (9.4 per cent by 2100). The net effect is that consumption and GNP fall by a higher proportion than GDP.

Climate change will have disproportionate effects on the prices of non-discretionary goods such as food and dwelling prices. 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. Additionally, those that derive income from wages are likely to be more adversely affected, on average, than those that derive income from capital or land.

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. Relative to the general price of goods in the economy, the cost of food is projected to rise by just over 15 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 11 per cent by 2100.

The modelling shows that climate change is unlikely to affect all income types uniformly (Table 1.3). While wage income falls substantially, non-wage income is less affected

Table 1.3 Changes to income types (per cent deviation from reference case)

Income type	2020	2050	2100
Income from labour	-1.0	-3.3	-9.5
Income from land	0.8	2.4	-1.7
Income from capital	-0.5	-1.6	-7.1

Source: MMRF

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 farming 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 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 8.5 per cent.

The economic impacts on developing countries are projected to be greater than the global average (see Table 1.4). This is important for Australia, as Australia's reliance on developing countries' demand

for its exports is projected to grow rapidly in the reference case, with China and India becoming Australia's largest trading partners representing 18% and 13%, respectively, of purchases of Australia's exports by 2100.

As such, Australia's terms of trade are projected to be affected more adversely by climate change (fall by 3 per cent³ by 2100) than those of any other country or region covered by the analysis. No other country or regional is even close.

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 associated changes in global production and demand for goods.

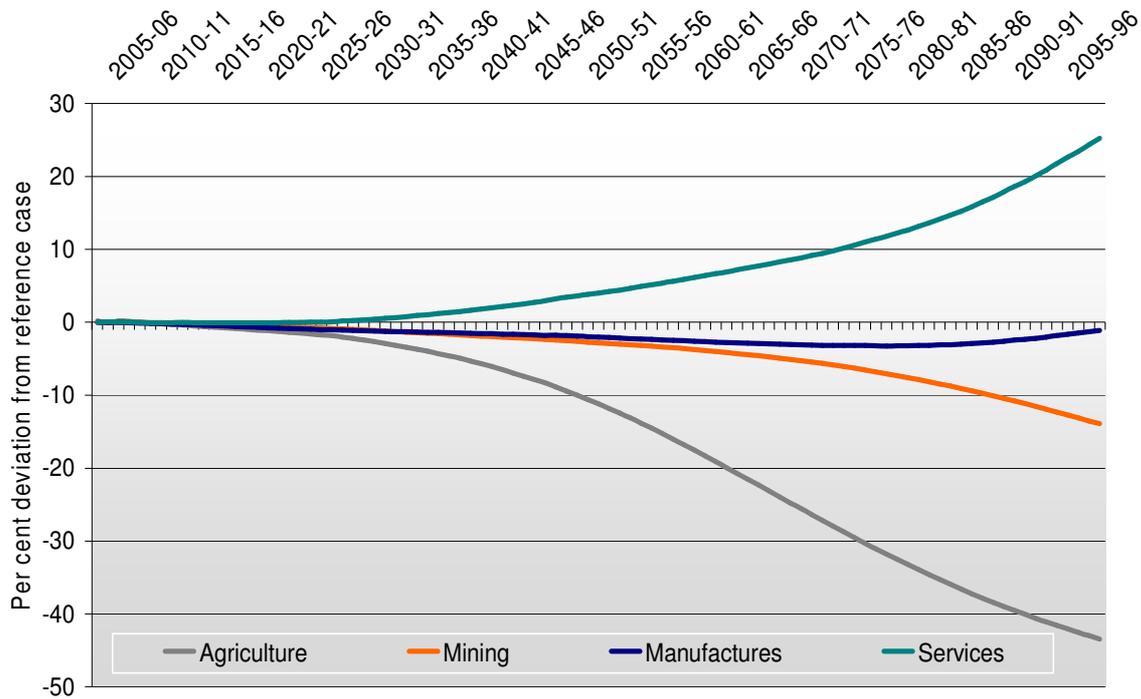
Table 1.4 Changes to terms of trade (per cent change from reference case)

	2050	2100
United States	-0.01	-0.73
European Union (25)	-0.01	-0.72
China	0.03	1.13
Former Soviet Union	-0.07	0.54
Japan	-0.01	-1.21
India	0.10	0.83
Canada	-0.10	0.48
Australia	-0.23	-2.95
Indonesia	0.12	1.43
South Africa	-0.10	-1.75
Other Asia	-0.01	0.09
Rest of OPEC	-0.16	-0.53
Rest of world	0.01	0.12

Source: GIAM

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 1.2. While exports of agriculture, mining and manufactured commodities are projected to decline, changes in the real exchange rates assist service exports.

Figure 1.2 Changes to export volumes, 2005–2100, Type 1 costs only



Source: MMRF

Industry impacts

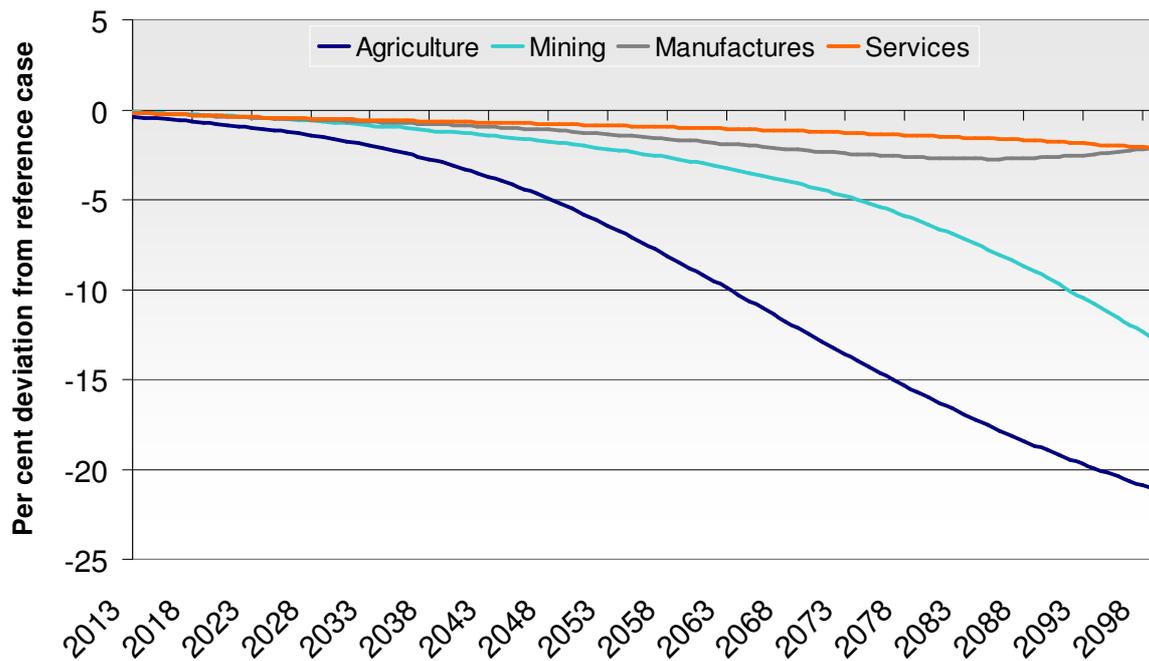
The MMRF model produces projections for 58 industries. While this can be useful for identifying those industries likely to be disadvantaged or advantaged by climate change, some caution is required when analysing the results. Since the Review has only considered a subset of impacts in the modelling, 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 difficulty 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 6 of the Final Report, increased temperatures and reduced rainfall are likely to cause substantial reductions in agricultural output. However, the decline in agricultural output is not as great as is implied by the productivity loss alone. Export volumes (Figure 1.1 above) 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 13 per cent, relative to the reference case, by 2100 (Figure 1.2 below). The coal industry's output is projected to decline by almost 8 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 for coal falls by almost 23 per cent, relative to the reference case¹³. Iron ore activity is also projected to decline, relative to the reference case, for much the same reason as for coal.

Figure 1.2 Changes to activity, 2005–2100. Type 1 costs only.



Source: MMRF

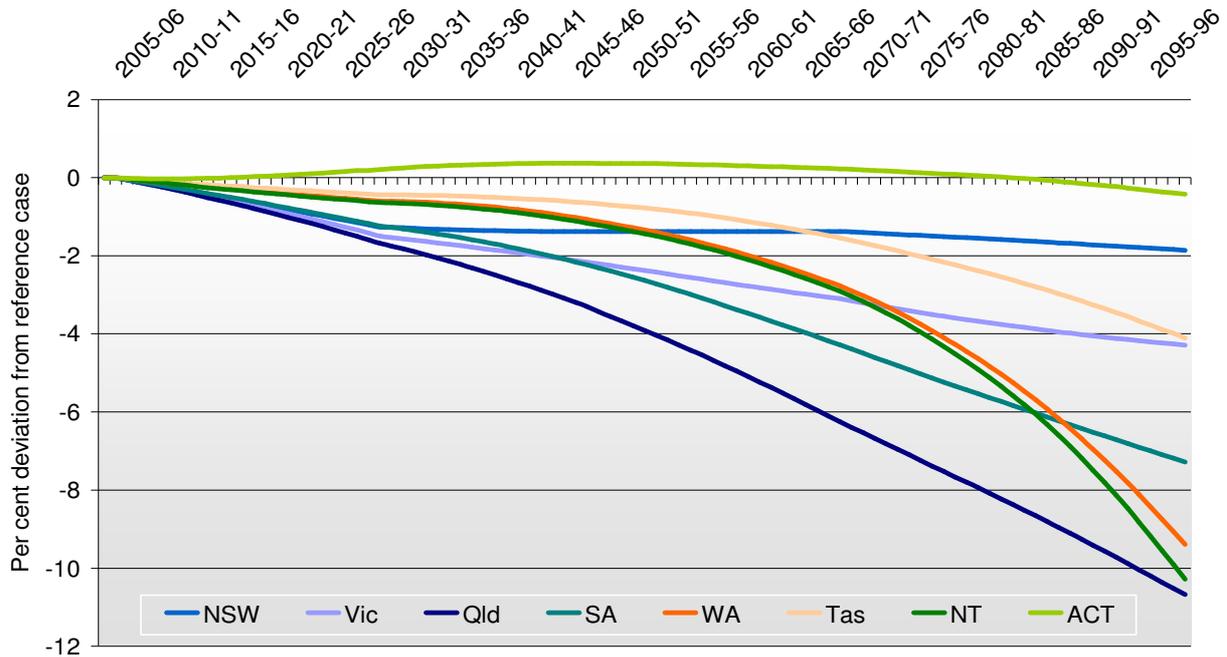
State and territory results

The impacts of unmitigated climate change will be experienced differently across States and Territories (Figure 1.3). Typically, impacts are most significant in regions that:

- are already subject to climate extremes and are likely to experience larger than average climate changes
- 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.

Some caution needs to be used in interpreting these results, since the Review was not able to consider all of the possible market effects of climate change. The exclusion of some impacts that are region specific is likely to underestimate effects relative to states and territories in which impacts are estimated more completely. For example, the impacts on demand for tourism from reduced environmental amenity of tourist assets (such as the Great Barrier Reef) have not been modelled. This is likely to lead to some underestimation of the costs to Queensland relative to other states and territories. Nevertheless the modelling does provide some useful insights into the main regional differences between states and territories that may arise from climate change and climate change mitigation.

Figure 1.3 Projected changes to gross state product, 2005-2099, Type 1 costs only



Source: MMRF

Queensland is projected to be most affected by climate change. Queensland has large export-orientated mining (especially coal) and agriculture (primarily beef, sugar and to a lesser extent cotton) sectors, both of which are expected to be adversely affected by climate change. Reductions in economic activity and hence employment opportunities, relative to the reference case, also slows the migration of people from interstate³.

Climate change is projected to have relatively large effects on GSP in Victoria and South Australia, with their agriculture sectors expected to be adversely affected by climate change.

The Northern Territory is less affected than Victoria and South Australia as its economy is less dependent on agriculture.

Western Australia is less affected in the first half of the century, since its agricultural sector is dominated by wheat, which initially benefits from the carbon dioxide fertilisation effect, and because early and moderate effects of reductions in rainfall moderate salinity effects. In the second half of the century, damages in Western Australia increase as climate change affects its agricultural output more strongly and negatively and world demand for mining commodities falls.

New South Wales is projected to be affected less than the Australian average as a result of climate change. It is relatively intensive in services, which is the sector least affected by climate change. The large effects on agricultural productivity are not as pronounced in NSW given the small contribution of agriculture to GSP in NSW. 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 as climate changes are projected to be small and its industries are less susceptible to climate damages. Tasmania's climate is relatively cool compared to the rest of Australia, and water resources are more abundant than in most other regions in Australia.

³ 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.

The main activity of the Australian Capital Territory relates to the running of government. Since the modelling assumes that real government consumption is relatively unaffected by climate change the activity in the Australian Capital Territory's is also relatively unaffected.

The contribution of individual climate change impacts to net economic impacts

In order to demonstrate the relative contribution of each impact area to the net economic effects of climate change, the Review has modelled each separately. Caution must be used in interpreting the results (shown in Table 1.5) as the results are not additive⁴.

Table 1.5 Projected changes to GNP 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

Source: MMRF

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. 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.

Agriculture

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 meat⁵.

The loss of productivity will result in agriculture drawing more resources from the economy in order to meet this inelastic demand and maintain production at levels justified by domestic and world demand and prices.

While the modelling 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.

Terms of trade changes from global impacts

The global modelling suggests that world GDP is likely to fall by around 8.5 per cent by 2100 with losses in developing countries likely to be higher than the global average. This is important as, by 2100, developing countries in our region are projected to become our major trading partners.

Health

The health-related impacts considered by the Review have relatively small economic effects and can be managed without large economic cost. While this appears sound provided the appropriate preventative health measures are undertaken, these results must be considered cautiously as the Review has only captured a component of the likely total health impacts.

Tropical cyclones

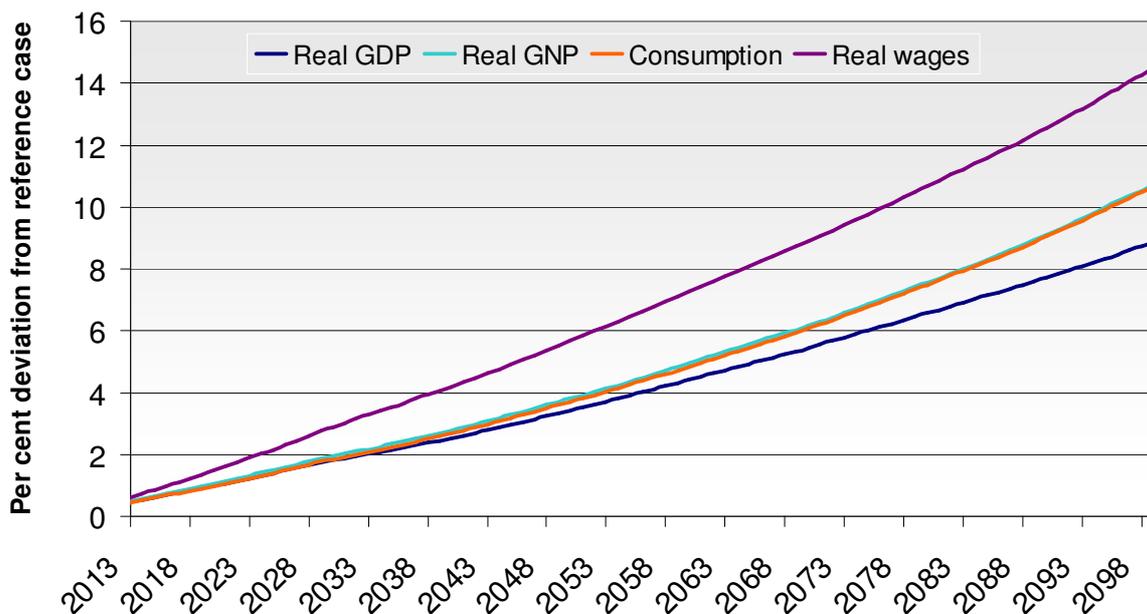
Taken as a series of annualised losses, the economic impacts of tropical cyclones are small. These results may be underestimated however, as it was not possible to consider either the impacts of flooding associated with cyclones or the impacts that might be associated with a southward shift in the genesis of tropical cyclones.

3 Sensitivity Analysis: The hot and dry case

Uncertainty in how the Australian climate will respond to a given global temperature is incorporated by considering a 'dry' rainfall sensitivity (relative to the median rainfall estimate) combined with a 'hot' temperature outcome. This sensitivity is associated with the 10th percentile rainfall outcome for Australia combined with a 90th percentile temperature outcome for Australia. Both are considered in the context of the same global mean temperature of 4.5°C by 2100.

Under the hot and dry unmitigated scenario the economic impacts are substantially higher than for the median unmitigated scenario (Figure 1.4). By 2100, the combined Type 1 and Type 2 costs are projected to amount to almost 14 per cent of consumption and GNP, and 12 per cent of GDP, relative to the reference case with no climate change. This compares to reductions of 10, and 8 respectively, for the median scenario.

Figure 1.4 The modelled market costs for Australia of hot and dry unmitigated climate change up to 2100 (Type 1 costs only; excluding Type 2).



Source: MMRF

The potential impacts of a global shock

More severe effects of climate change could trigger social and political disruption in developing nations with less stable political systems and high vulnerability to climate change. This would have flow on consequences for developing nations, including Australia, through international trade, defence, and foreign aid responses. At the same time, more severe global climate change effects could result in economic disruption within developing countries as nations deal with dislocation in developing countries and at the same time experience severe effects of climate change domestically. What then might be the impact if climate change resulted in widespread shocks occurring in the rest of the world simultaneously? What would the impact of such a “global shock” be?

To illustrate the potential importance of such a situation, the Review modelled a highly illustrative sensitivity in which the loss in total factor productivity was approximately four-fold higher for a temperature change of 4°C. This is equivalent to the impact of the American Great Depression which caused a decline in GDP of 30 per cent. Such a loss in total factor productivity could be feasible, particularly if extreme climatic events result in periods of prolonged social and political unrest.

Under this scenario, global real GDP is projected to fall by 26 per cent, relative to the reference case by 2100. This is substantially higher than the 8 per cent loss projected under the median unmitigated future. As a result, global real GDP would grow by 5.8 times over the period to 2005–2100 instead of 7.2 times in the median unmitigated future.

In Australia real GDP is projected to fall by around 2.6 per cent, relative to the reference case by 2050. By 2100, the effects on Australia’s GDP are significantly more pronounced, with GDP projected to fall by around 17.7 per cent, relative to the reference case.

Note that these results were not reported in the final Report of the Garnaut Climate Change Review.

¹ The terms of trade describe the ratio of export to import prices.

² 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.

³ 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.

⁴ 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.

⁵ 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.