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climate change

impacts on Australian agriculture

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- *Agriculture plays an important role in the global and Australian economies. However, potential changes in climate may reduce productivity and output in agricultural industries in major producing countries, including Australia, in the medium to long term.*
- *ABARE analysis indicates that future climate changes and associated declines in agricultural productivity and global economic activity may affect global production of key commodities: for example, global wheat, beef, dairy and sugar production could decline by 2–6 per cent by 2030 and by 5–11 per cent by 2050, relative to what would otherwise have been the case (the 'reference case').*
- *Furthermore, Australian production of these commodities could decline by an estimated 9–10 per cent by 2030 and 13–19 per cent by 2050, relative to the reference case.*
- *These changes would also have significant implications for international agricultural trade. For example, Australian agricultural exports of key commodities are projected to decline by 11–63 per cent by 2030 and by 15–79 per cent by 2050, relative to the reference case.*
- *Australia is projected to be one of the most adversely affected regions from future changes in climate in terms of reductions in agricultural production and exports.*
- *There is a continuing need for the agriculture sector to maintain strong productivity growth in order to cope with the potential pressures emerging from climate change. In this context, adaptation measures, including improved agricultural technologies, will be particularly important in reducing the potential impacts.*
- *There is also an urgent need for policies that encourage rather than impede adjustment in vulnerable sectors in agriculture, including already marginal farming enterprises.*
- *In order to respond to climate change in an efficient manner and maintain and enhance the productivity and international competitiveness of Australian industries, further research and development is required in both climate change adaptation and mitigation technologies and measures.*

introduction

There is broad agreement among the international scientific community that the global climate has been changing and will continue to change (IPCC 2007a). According to the current scientific literature, human induced increases in the atmospheric concentration of greenhouse gases will continue to drive changes in climate across the globe, including Australia, for the foreseeable future (IPCC 2007a; PMSEIC 2007). The projected changes in climate are likely to be associated with a range of biophysical, environmental, social and economic impacts across a range of sectors and throughout the world (Stern 2006; Garnaut 2007). Agriculture is an important sector domestically and globally that is likely to be affected directly and indirectly by climate change.

Although agriculture contributes only about 2 per cent of gross domestic product (GDP) in Australia (ABARE 2007), around two-thirds of agricultural products are exported (DAFF 2007) and exports of agricultural products account for about 18 cent of total Australian merchandise exports (ABARE 2007). In 2005, Australia was the world's largest exporter of wool and the second largest exporter of beef and veal, mutton and lamb, wheat and sugar (ABARE 2007). Manufacturing of food, beverages and tobacco contributes a further 2 per cent to Australia's GDP (ABARE 2007).

In this article, the potential medium to long term economic and agricultural trade impacts of potential changes in climate on Australian and global agriculture sectors are investigated.

projected changes in climate

In this section, a brief overview of the potential future changes in climate, as reported in recent domestic and international scientific literature, is presented. The contribution of anthropogenic (human induced) greenhouse gas emissions to rising atmospheric concentrations of these gases is expected to lead to a range of regionally differentiated changes in key climate variables, including temperature, rainfall patterns and extreme weather events.

temperature

Given a range of potential greenhouse gas emissions pathways, global mean surface air temperatures are projected to increase by between 1.1 and 6.4 degrees Celsius by the end of the century, relative to 1980–99 (IPCC 2007b). The projected increase in temperatures over land masses is expected to be greater than the global average because of lower evaporative cooling and a smaller thermal inertia compared with the oceans. Temperature increases comparable to the global average are considered likely in parts of south east Asia, southern South America, Australia and New Zealand. Increases in temperatures above the global average are likely throughout Africa, central, northern and eastern Asia, the Tibetan plateau, most of south and central America and in north America and Europe (IPCC 2007b). In northern parts of north America and in northern Europe warming is projected to be greatest in winter. However, in southern North America and mediterranean Europe the greatest warming is expected to occur in summer (IPCC 2007b).

precipitation

As reported by the Intergovernmental Panel on Climate Change (IPCC 2007b), projected changes in precipitation are less certain than changes in temperatures, and rainfall patterns are projected to vary widely between different regions. Annual average rainfall is expected to increase in the Asian monsoon region, eastern Africa, northern

Europe, Canada, north eastern United States and western areas on the South Island of New Zealand (IPCC 2007b). However, rainfall is projected to decrease in northern Saharan Africa, mediterranean Africa and Europe, south western United States and central America. Changes in seasonal rainfall patterns are also expected, with winters becoming wetter in central Europe, northern, eastern, southern and south east Asia and the Tibetan Plateau. Summers are projected to be drier in central Europe, central Asia and southern Canada and wetter in northern, eastern, southern and south east Asia and south eastern South America (IPCC 2007b).

extreme events

The IPCC (2007b) has also found that changing temperature and rainfall patterns are likely to result in more severe extreme events, such as droughts, floods and tropical cyclones. Land affected by extreme drought is expected to increase significantly by the end of the century (IPCC 2007b). Southern Australia and mediterranean and central Europe are all expected to experience increased risk of drought over the next century. Heat waves in eastern Asia are expected to increase in frequency, intensity and length. Extreme daily high temperatures are projected to become more frequent in Australia and New Zealand. Conversely, the number of frost days is expected to fall and thereby increase the growing seasons especially in parts of North America, Europe and central and northern Asia. Overall, tropical storms and cyclones are expected to become less frequent. However, the average intensity of tropical cyclones is projected to increase. Precipitation events are in general projected to become more intense, with longer dry periods between events. These extreme precipitation events, as well as snow and glacier melt and rising sea levels, are expected to lead to an increase in floods (IPCC 2007b).

climate projections for Australia

temperature

Given a range of potential future global greenhouse gas emissions pathways, as reported in the IPCC's Special Report on Emission Scenarios (IPCC 2000), the average temperature in Australia is projected to increase by 1–5 degrees Celsius at 2070 compared with 1990 (CSIRO and BoM 2007, table 1). The increase in temperature is expected to vary between regions in Australia. Warming is expected to be greatest in inland areas and least in coastal and mountainous regions. By 2030, average annual temperatures are projected to be about 1 degree Celsius higher, but inland areas may experience increases of up to 1.8 degrees. Warming is expected to be most severe in the north west of Australia and mildest in the south and east. There is also expected to be seasonal differences in warming patterns, with mean warming in winter months projected to be less than in other seasons.

1 projected increases in average temperatures in Australia
compared with 1990

	2030 °C	2050 °C	2070 °C
Australia	1.0	0.8 – 2.8	1.0 – 5.0
coastal	0.7 – 0.9		
inland	1.0 – 1.2		

Source: CSIRO and BoM (2007).

rainfall

Best estimate projections from the CSIRO and BoM (2007) indicate potentially little change in precipitation for northern Australia and decreases of around 10 per cent

2 projected future changes in precipitation in Australia
compared with 1990

annual	2030 %	2050 %	2070 %
northern areas (and central and eastern for 2050 and 2070)	-10 to +5	-20 to +10	-30 to +20
southern areas	-10 to 0	-20 to 0	-30 to +5
winter and spring			
south east	-10 to 0	-20 to 0	-35 to 0
south west	-15 to 0	-30 to 0	-40 to 0
eastern areas	-15 to +5	-20 to +10	-40 to +15
summer and autumn	-15 to +10	-20 to +15	-40 to +30

Source: CSIRO and BoM (2007).

in southern areas by 2070, relative to 1990. Changes in precipitation levels are also expected to vary widely across regions and seasons in Australia. Although northern Australia is projected to experience little change in rainfall levels over the next sixty years, south western areas in Australia are projected to experience decreased rainfall of up to 40 per cent by 2070 in winter and spring. The decreases in rainfall are projected to be greatest in winter and spring across Australia (table 2).

extreme events

CSIRO and the Bureau of Meteorology project that there will be up to 20 per cent more drought months over most of Australia by 2030. By 2070, up to 40 per cent more drought months are projected in eastern Australia and up to 80 per cent more in south western Australia. Extreme daily precipitation events are expected to become more frequent in the north but less frequent in the south. Throughout Australia, precipitation events are projected to become heavier and be followed by longer dry spells. This is expected to lead to an increased occurrence of floods and erosion of soils (CSIRO and BoM 2007). Hotter and drier conditions are also expected to increase fire risk, particularly in south eastern Australia. Similar to global projections, the Australian region is likely to experience an increase in the proportion of intense tropical cyclones, but a possible decrease in the total number of cyclones (CSIRO and BoM 2007).

climate change impacts on agriculture

Given the projected changes in key global and regional climate variables, one of the key sectors vulnerable to climate change is agriculture, both in Australia and globally. Changes in water availability, water quality, temperatures and pests and diseases are all likely to have an impact on agricultural productivity.

It is important to recognise that potential impacts of climate change are unlikely to be uniformly distributed around the world. Increasing temperatures may extend the growing season for crops in some areas but increase the demand for water by crops and decrease yields in other areas (Ecofys BV 2006). In colder regions higher temperatures are likely to reduce cold related livestock deaths while warmer regions could experience increased heat stress in livestock (Ecofys BV 2006). Projected impacts of climate change on different agricultural industries globally are presented in table 3.

3 projected climate change impacts on global agriculture

region and sector/industry	temperature change/ CO_2 concentration/ year	projected impact % change	source
world			
agricultural production	global average temperature increase of 2.8–5.2°C by 2100, relative to 1990	–0.8 to –0.3, relative to 1990	ERS 2001
aggregate crop production	global average temperature increase of 2.8–5.2°C by 2100, relative to 1990	–1.3 to –0.5, relative to 1990	ERS 2001
south east Asia			
aggregate crop production	global average temperature increase of 2.8–5.2°C by 2100, relative to 1990	–4.8 to –2.6, relative to 1990	ERS 2001
China			
wheat yields	1°C	–5.4 to –1.5	You et al. 2005
India			
wheat yields	0.5–1.5°C	–2 to –5	IPCC 2007a
Bolivia			
cattle production	4°C	up to –20	IPCC 2007a
Africa			
net income from livestock	2100	–54, relative to current levels	Seo & Mendelsohn 2007
Japan			
aggregate crop production	global average temperature increase of 2.8–5.2°C by 2100, relative to 1990	+6.2 to +10.4, relative to 1990	ERS 2001
southern Europe			
legume yields	2050	–30 to +5, relative to baseline	IPCC 2007a
northern Europe wheat yields	2080	+10 to +30, relative to baseline	IPCC 2007a
Canada			
cow/calf/dairy production	5°C	–10	Lemmen & Warren 2004
United States			
total agricultural production	global average temperature increase of 2.8–5.2°C by 2100, relative to 1990	–0.9 to +1.7, relative to 1990	ERS 2001
aggregate crop production	global average temperature increase of 2.8–5.2°C by 2100, relative to 1990	–0.7 to +3.8, relative to 1990	ERS 2001
crop agriculture	global average temperature increase of 2.4°C by 2100, relative to 2000	average annual change 2000–2100 –25.8 to +20.4	Jorgenson et al. 2004 (central estimates)
wheat yields	0.8°C	+2.4	USDA 2007
dairy milk production	doubling of CO_2	–2.2 to –2.1	USDA 2007
livestock production	doubling of CO_2	–1.3 to –0.5	Crosson 1997

In Australia, projected higher temperatures and lower rainfall are expected to reduce agricultural production, relative to what would otherwise be the case ('reference case'). Increases in carbon dioxide concentration could have positive carbon fertilisation effects by increasing the rate of photosynthesis in some plants (Steffen and Canadell 2005). However, higher concentrations of carbon dioxide could also reduce crop quality, by lowering the content of protein and trace elements (EEA 2004). The positive impacts of carbon fertilisation are likely to be restricted by high temperatures and low rainfall, which are both expected to occur in Australia (Amthor 2001).

Cline (2007) projects that future potential climate changes could lower agricultural productivity in Australia by 27 per cent (without carbon fertilisation) and by 16 per cent (with carbon fertilisation) by 2080. World agricultural production could potentially fall by 16 per cent (without carbon fertilisation) and by 3 per cent (with carbon fertilisation) by 2080 (Cline 2007).

Extreme events such as flooding and droughts are projected to increase in frequency and severity as the global climate changes. Such events are likely to reduce agricultural productivity and production by decreasing crop yields and increasing stock losses (Ecofys BV 2006). Changes in temperatures are also projected to alter the incidence and occurrence of pests and diseases. For example, Queensland fruit fly is expected to spread southwards in response to future higher temperatures, reducing yields and increasing costs to the Australian agriculture sector. However, the range of the light brown apple moth, for example, is expected to contract following changes in projected climatic conditions (Preston and Jones 2006).

The projected impacts of climate change on different agricultural industries in Australia are presented in table 4.

4 projected climate change impacts on Australian agriculture
for given changes in temperature relative to 1990

change in temp.	sector / industry	impact	source
< 1°C	annual milk production per cow	fall by 250–310 litres or 6 per cent	Preston and Jones 2006
	total factor productivity of wheat in NSW with lower rainfall	–4.2 per cent, relative to reference case	Heyhoe et al. 2007
	total factor productivity of wheat in WA with lower rainfall	–7.3 per cent, relative to reference case	Heyhoe et al. 2007
	total factor productivity of sheep meat in NSW with lower rainfall	–1.8 per cent, relative to reference case	Heyhoe et al. 2007
	total factor productivity of sheep meat in WA with lower rainfall	–6.1 per cent, relative to reference case	Heyhoe et al. 2007
1–2°C	pasture productivity with 20 per cent lower precipitation	–15 per cent	Crimp et al. 2002
	liveweight gain in cattle with 20 per cent lower precipitation	–12 per cent	Crimp et al. 2002
3–4°C	tick related losses in net cattle production weight	increase by 128 per cent	Preston and Jones 2006

potential economic impacts of climate change on Australian and global agriculture

Given the potential for future changes in key climate variables, it is important to understand the potential impacts on different industries. In this article, the potential medium to long term economic impacts of future changes in climate on Australian and global agriculture are illustrated within the context of two important factors – productivity impacts and trade impacts. The economic impacts of climate change on a certain country's agricultural production depend not only on how production potential is affected within the country by changes in climate variables, but also on how potential changes in both agricultural and nonagricultural productivity affect import demands and export supplies of farm products in other regions of the world.

productivity impacts

Potential changes in key climate variables, such as increased average temperatures, changed rainfall patterns and increased climate variability, are projected to directly affect agricultural productivity (AGO 2007). There may also be indirect impacts on agricultural productivity through changes in the incidence of pests and diseases and increased rates of soil erosion and degradation. The effect of changes in climate on agricultural productivity is likely to vary between different countries (Cline 2007) and across different crop and livestock industries. For instance, crop production is likely to be affected directly by changes in average rainfall and temperatures, and by possible changes in distribution of rainfall during the year. The productivity of certain livestock industries will be influenced by changes in the quantity and quality of available pasture, as well as by the direct effects of temperature changes (Adams, Hurd and Reilly 1999).

The impact of potential changes in climate on agricultural productivity is uncertain, with estimates ranging from a small loss to a potential gain (Stern 2006). At increases in local average temperatures above 3 degrees Celsius, the potential for global food production is projected to decline (IPCC 2007a). According to Cline (2007) the projected reduction in agricultural productivity as a result of potential changes in climate within this century could lead to a decline in agricultural output in many regions in the medium to long term, with developing countries projected to experience much larger declines than developed countries.

trade impacts

Agricultural trade impacts of future changes in climate are likely to arise from the interaction of two forces – first, from a potential reduction in agricultural output in key producing countries brought about by changes in key climate variables and, second, from a slowdown in global economic activity brought about by climate change related effects that may be associated with a decline in demand for agricultural products in some regions. In this context it is important to recognise that the likely change in demand for agricultural commodities, such as grains, in response to changes in income is likely to be relatively low across many regions given their importance in meeting dietary requirements. On the other hand, the likely change in demand for dairy and livestock products in response to changes in income is likely to be relatively high, particularly in key developing countries.

box 1 **analytical framework**

GTEM
ABARE's global trade and environment model (GTEM) is a dynamic, multiregion, multisector, general equilibrium model of the world economy. The model provides a useful framework for analysing economywide and sectoral impacts, including those resulting from, for example, a slowdown in global economic activity and productivity changes in different sectors in an economy brought about by climate change. The GTEM framework takes into account the interactions between different sectors and other agents in an economy and captures the interactions between economies through trade. It can be used to estimate the impacts of the changes in policies or events on key economic variables. Full documentation of the model is available on ABARE's website (**abare**conomics.com).

Ausregion
ABARE's Ausregion model is a dynamic computable general equilibrium model of the Australian economy, with representation of all states and territories. Ausregion has a comprehensive coverage of sectors that are important to Australia. The model provides a useful framework for analysing economywide and sectoral impacts, including those resulting from, for example, productivity changes in different agricultural industries at state/territory level. Details of the model are also available on ABARE's website.

interface
The two models have unique characteristics that, when used together, provide a robust and rigorous framework for analysing policy issues that have international, national, sectoral and state level impacts. The interface between the models is illustrated below:

model interface

- GTEM is used to assess the country/region economic and trade implications of a slowdown in global economic activity and change in agricultural productivity in key countries/regions over the medium to long term driven by potential changes in climate.
- Ausregion is used to assess the state/territory implications of changes in agricultural productivity in Australia driven by future potential changes in climate over the medium to long term, while taking into account the international trade implications of a slowdown in global economic activity and a decline in agricultural productivity in key countries/regions.
- Successive iterations of the Ausregion and GTEM model simulations are undertaken to validate and ensure consistency of the state/territory economic and trade implications in Australia of a global slowdown in economic activity and agricultural productivity changes driven by potential changes in climate over the medium to long term.

analysing the economic impacts of climate change on agriculture

declines in global agricultural productivity and a slowdown in global economic activity

An illustrative scenario is analysed here to investigate potential medium to long term economic and trade impacts of potential changes in climate on global and Australian agriculture. The scenario assumes that no significant global climate change response measures emerge to substantially mitigate the potential medium to long term impacts of climate change. Furthermore, the scenario assumes no planned adaptation in agriculture in terms of strategic responses in anticipation of expected changes in climate. The results of this scenario are compared against a reference case in which it is assumed that there are no climate change impacts on future economic growth. It is important to recognise that there remain uncertainties in both the potential changes in climate and impacts on industry at the regional and sectoral level. The results presented in this article are illustrative and are designed to provide insights into the potential direction and order of magnitude of likely medium to long term impacts only, rather than precise forecasts.

Under the scenario, based on Cline (2007), it is assumed that agricultural productivity in the major producing regions of the world, including Australia, will decline over the medium to long term because of projected changes in climate. Furthermore, it is also assumed that there will be adverse impacts on productivity in many nonagricultural sectors, driven by the impacts of changes in climate. Based on Stern (2006), it is assumed that there will be an overall slowdown in global economic activity driven by climate change in the medium to long term across key regions. The purpose of the scenario is to illustrate how a slowdown in global economic activity, including overall declines in agricultural productivity, in response to potential changes in climate, may affect global farm production and trade in the medium to long term.

The results from this global scenario analysis are then used to illustrate the impact of potential changes in climate on key agricultural industries in major regions in Australia. This analysis takes into account two important factors: first, the potential international trade implications of a slowdown in global economic activity associated with a decline in global agricultural and nonagricultural productivity driven by potential changes in climate; and second, potential differential impacts across varying farming regions in Australia driven by future potential climate change, following Cline (2007).

A brief description of the analytical framework and interface between the models used is provided in box 1.

assumptions

Potential changes in key climate variables may reduce global agricultural productivity in the medium to long term. In this analysis, estimates of the potential impacts of climate change on regional agricultural productivity from a recent study by Cline (2007) are used.

Using a range of climate models with other modelling techniques and statistical tools relating agricultural productivity to climate variables, and applying a consistent methodology to more than 100 countries, regions and subregions within the larger countries, Cline (2007) estimated the potential changes in agricultural productivity for a wide range of countries and regions to 2080. Cline projected that global agricultural output at 2080 could be 3–16 per cent less (depending on the impacts of carbon fertilisation), compared with what would otherwise be the case, as a result of climate change. The greatest reduction in agricultural productivity is likely to occur in the developing countries. For modelling purposes, these projected impacts have been adjusted to 2050.

The assumed changes in agricultural productivity in response to future climate change that are used in the modelling in this article are based on Cline (2007) and are provided in tables 5 and 6. It is evident from table 5 that the potential decline in agricultural productivity in response to climate change will vary between different regions. Hence, the implications for global agricultural production and trade can be influenced by the differential productivity declines in different regions. In general, agricultural production systems in countries located in the lower latitudes, primarily developing countries, are expected to be most adversely affected. Mid to high latitude countries are expected to experience limited losses or even benefit from changes in agricultural production brought about by climate change (Rosenzweig and Tubiello 2007). Given the paucity of information, it is assumed in the current analysis that climate change is likely to result in productivity changes across different agricultural activities to a similar degree in a particular region. However, it is important to recognise that the impacts of climate change on agricultural productivity are likely to differ across different activities.

According to Stern (2006), potential changes in climate can affect long term global economic activity through at least three processes: through market impacts (for example, through impacts on the energy sector and coastal regions); through nonmarket impacts (impacts on the environment); and through the risk of catastrophic impacts (such as cyclones). These impacts highlighted by Stern are also likely to adversely affect the productivity of many nonagricultural sectors. Taking into account these potential impacts, Stern provided a range of equivalent measures of medium to long term global economic impacts of potential changes in climate. These impacts range widely and increase up to around 35 per cent in terms of losses under extreme climate change scenarios. In assessing the economic impacts of climate change, Stern (2006) used a low discount rate. That low rate has been commented on by Tol and Yohe (2006), Nordhaus (2007), Weitzman (2007), Dasgupta (2007) and Mendelsohn (2007). The size of the discount rate used has important implications for the magnitude of the impact of climate change in the distant future and the most appropriate policy response. A very low discount rate magnifies large damages as a result of climate change in the far-distant future into a large current value (Nordhaus 2007). Given this background, and based on Stern (2006), in the modelling analysis in this article it has been assumed that in developed and developing countries economic activity will decline by 5 per cent and 10 per cent respectively by 2050, relative to what would otherwise be the case, as a result of potential changes in climate.

5 projected changes in agricultural productivity from climate change without carbon fertilisation at 2050 relative to the reference case

	%
Australia	-17
China	-4
Japan	-4
New Zealand	+1
ASEAN	-12
India	-25
Canada	-1
United States	-4
Rest of Europe	-4
Argentina	-7
Brazil	-10
Least developed countries	-18
European Union	-4
Rest of the world	-13

Source: Based on Cline (2007).

6 projected change in agricultural productivity in Australia from climate change without carbon fertilisation at 2050 relative to the reference case

	%
Australia	-17
– south east	-7
– south west	-9
– north	-27

Source: Based on Cline (2007).

Based on the estimates of adverse impacts of potential future changes in climate on a range of countries and regions provided in Cline (2007) and Stern (2006), potential agricultural and nonagricultural sector productivity declines to 2050 are simulated using ABARE's GTEM model to assess the resulting changes in agricultural production and trade in key regions of the global economy. If the impacts of climate change on productivity are larger than those modelled in this article, the impacts on agricultural production and trade would be magnified.

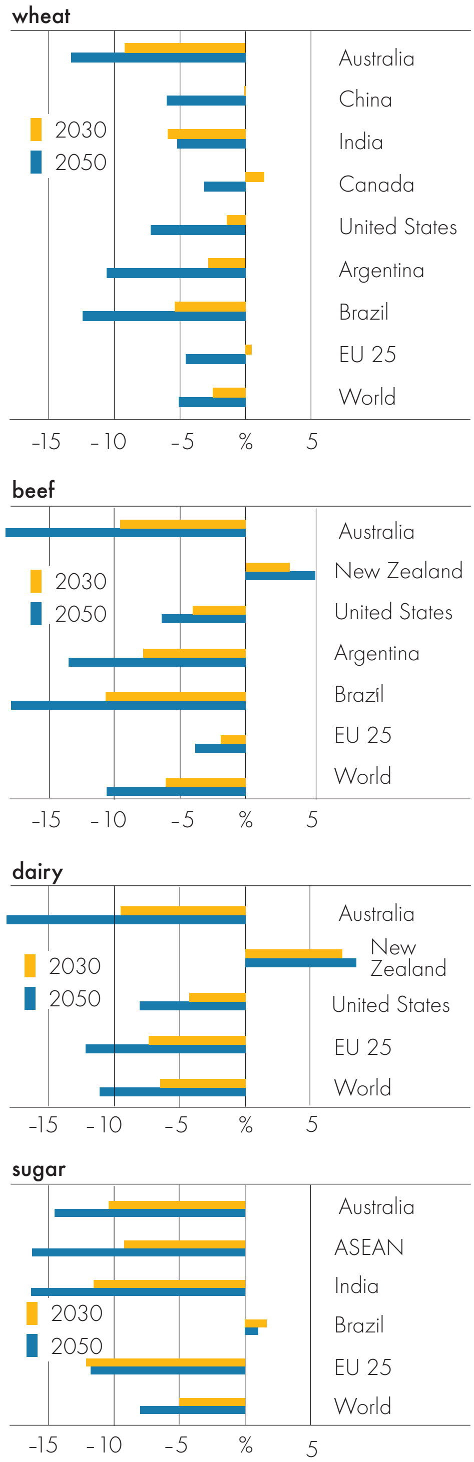
simulation results

change in global agricultural production

Potential changes in key climate variables are projected to result in a loss of agricultural productivity, declines in crop yields, pasture growth and livestock production returns and a rise in agricultural production costs, leading to a loss in competitiveness and, hence overall output. Furthermore, a slowdown in global economic activity driven by climate change related effects is likely to result in a decline in the demand for agricultural products in some regions. As indicated earlier, the likely magnitude of the decline in demand for agricultural commodities can vary depending on the degree of demand responsiveness to changes in income and prices in different countries/regions with respect to different farm products.

The impact of a slowdown in global economic activity and a reduction in agricultural productivity of farm output is shown in figure A, based on analysis using ABARE's GTEM model. The modelling results are reported here only for key countries and major internationally traded farm products. The detailed Australian results (based on the GTEM–Ausregion modelling interface) are discussed separately toward the end of this section. The modelling results show that as a result of potential future changes in climate, global wheat production is estimated to decline by 2.5 per cent at 2030 and 5.1 per cent at 2050; beef by 6.1 and 11 per cent; dairy by 6.5 and 11 per cent; and sugar by 5.0 and 8.0 per cent respectively, relative to the reference case.

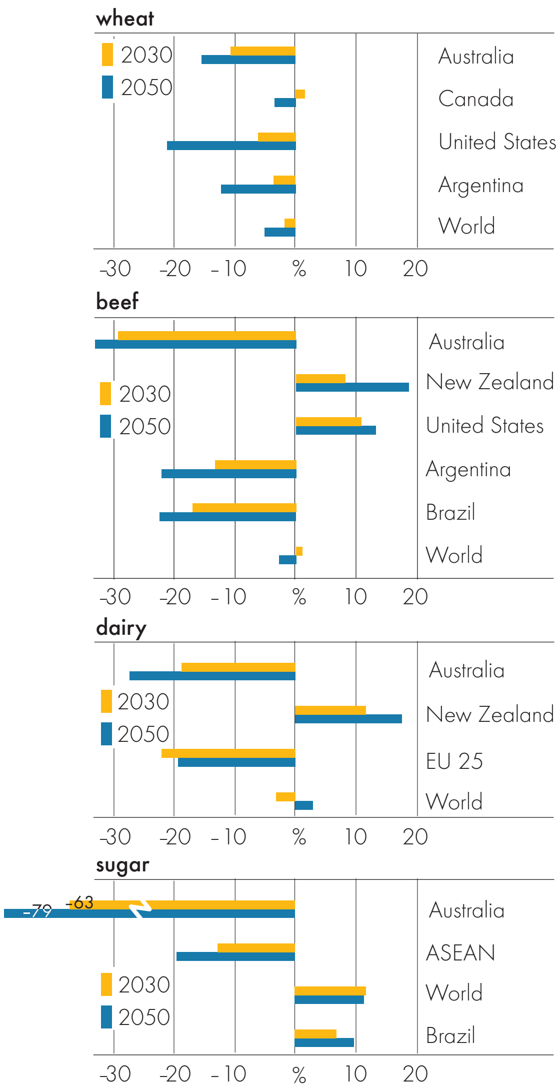
fig A **changes in global agricultural production** relative to the reference case



Wheat production is projected to be most affected in developing countries, such as Argentina and Brazil and also in Australia. Similarly, Argentina, Brazil and Australia are expected to be most adversely affected for beef production. Sugar production in India and ASEAN countries (particularly Thailand) is projected to be most adversely affected. However, given the relative comparative advantage of Brazilian sugar production, sugar output in Brazil is expected to expand, relative to the reference case. In the developed countries, US wheat, beef and dairy production is likely to be fairly significantly affected by future climate change and an associated slowdown in global economic activity, as illustrated in figure A. Furthermore, production of wheat, beef, dairy and sugar in the European Union is also likely to decline in 2050 relative to the reference case. Given the assumed increases in New Zealand's agricultural productivity, as reported in Cline (2007), output of New Zealand dairy and beef is expected to expand, relative to the reference case.

In box 2, other projections of climate change impacts on agricultural production are presented for comparison purposes.

fig B **changes in global agricultural exports** relative to the reference case



changes in global agricultural exports

The slowdown in economic activity combined with regionally differentiated declines in productivity resulting from potential changes in climate will also have important implications for international trade patterns in agricultural commodities (figure B).

Global wheat exports are projected to fall by about 1.8 per cent at 2030 and 5.1 per cent at 2050, relative to the reference case. Wheat exports are projected to decline in developed countries such as the United States.

Beef export volumes are expected to increase slightly by 2030, but as the major beef exporters then suffer from greater productivity losses, world beef exports are expected to fall by 2.8 per cent at 2050, relative to the reference case. Beef exports from Argentina and Brazil are expected to be most adversely affected.

Dairy export volumes are projected to fall by around 3.2 per cent at 2030, relative to the reference case, because of reduced productivity and economic activity brought about by climate change. However, at 2050 world dairy exports are projected to increase by 2.9 per cent relative to the reference case. This is likely to occur as changes in relative comparative advantage and resource reallocations take effect and production and exports are concentrated in more productive dairy producing countries such as New Zealand.

World sugar exports are projected to increase by 6.9 per cent at 2030 and 9.7 per cent at 2050, relative to the reference case. This reflects redistribution effects from different productivity losses across regions, with shifts in relative comparative advantage and resource reallocations to more efficient countries. In particular, Brazil is projected to increase its already substantial share in sugar exports. Exports of sugar from ASEAN countries (particularly Thailand) are projected to be adversely affected.

changes in Australian agricultural production

The impacts on Australia of assumed global developments (slowdown in global economic activity and a decline in agricultural productivity) and domestic developments (a decline in agricultural productivity in key growing regions) are assessed here using ABARE's GTEM–Ausregion modelling interface (box 1).

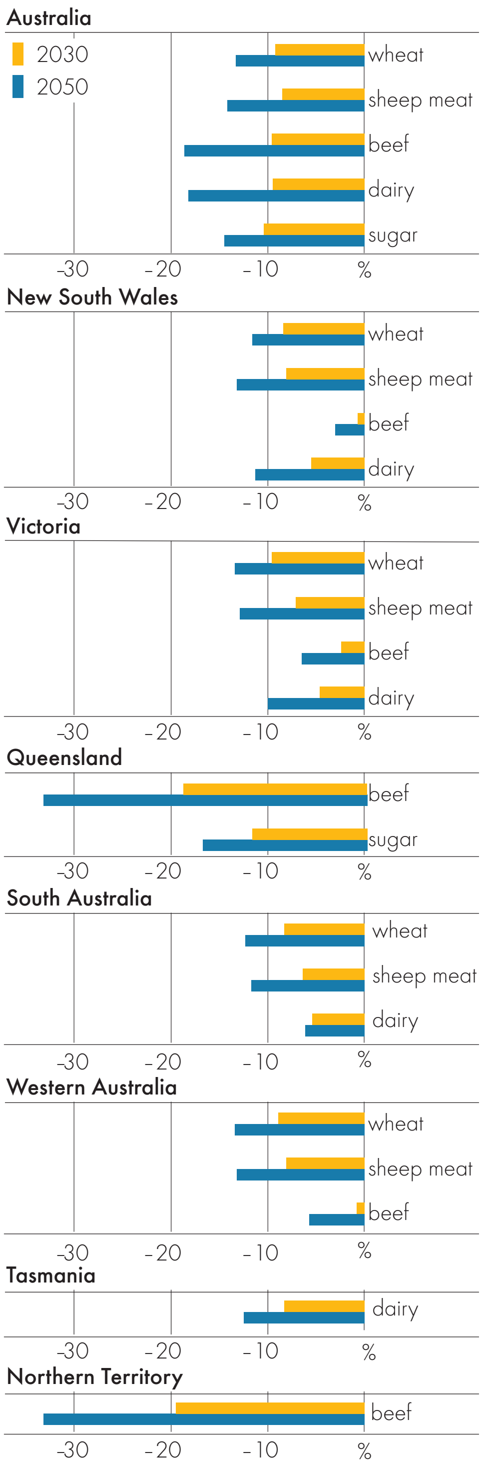
Overall, the modelling results indicate that, with assumed changes in climate, Australian production of key agricultural products is estimated to decline – wheat by 9.2 per cent at 2030 and 13 per cent at 2050; beef by 9.6 and 19 per cent; sheep meat by 8.5 and 14 per cent; dairy by 9.5 and 18 per cent; and sugar by 10 and 14 per cent respectively, relative to the reference case (figure C). Australia is projected to be one of the most adversely affected regions from declines in agricultural production driven by climate changes.

As shown in figure C, the output effects on key agricultural industries in each relevant state or territory are broadly in line with the likely productivity impacts indicated in table 6.

The modelling results indicate that wheat production across the states is estimated to decline by 8.3–9.6 per cent at 2030 and 12–13 per cent at 2050, relative to the reference case, in New South Wales, Victoria, South Australia and Western Australia (figure C). As a result of potential changes in climate, output in the sheep meat industry in New South Wales, Victoria, South Australia and Western Australia is estimated to decline by 6.4–8.1 per cent at 2030 and 12–13 per cent at 2050, relative to the reference case.

Output in the beef industry in New South Wales, Victoria, Queensland, Western Australia and Northern Territory is estimated to decline by between 0.7–20 per cent at 2030 and 3.0–34 per cent at 2050, relative to the reference case, as a result of potential changes in climate (figure C). Dairy industry output is also estimated to fall at 2030 and 2050

fig C **Australian agricultural production**
relative to the reference case

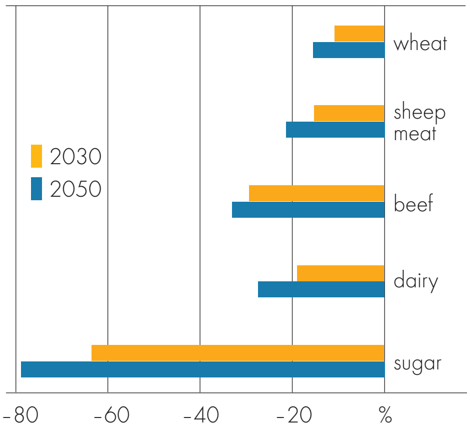


respectively by between 4.6–8.3 per cent and 6.1–12 per cent in New South Wales, Victoria, South Australia and Tasmania, relative to the reference case. Sugar industry output in Queensland is estimated to decline by 12 per cent at 2030 and 17 per cent and 2050, relative to the reference case. Australia is projected to be one of the most adversely affected regions.

changes in Australian agricultural exports

The changes in international trade in farm commodities resulting from the slowdown in global economic activity combined with a decline in agricultural productivity have important implications for Australian farm exports, as highlighted earlier. As shown in figure D, the modelling results indicate that, with potential changes in climate, Australia's exports of key agricultural products are likely to decline: wheat by an estimated 11 per cent at 2030 and 15 per cent at 2050; beef by 29 and 33 per cent, sheep meat by 15 and 21 per cent; dairy by 19 and 27 per cent; and sugar by 63 and 79 per cent respectively, relative to the reference case. Australia is projected to be one of the most adversely affected regions

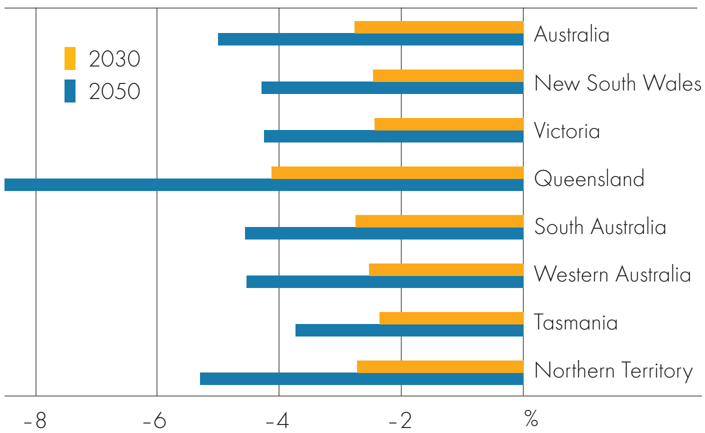
fig D **changes in Australian agricultural exports** relative to the reference case



impact on gross state product in Australia

The potential impacts of the reduction in productivity and agricultural production and exports driven by potential changes in climate on gross state products (GSP) and Australian gross domestic product (GDP) are shown in figure E. Future changes in climate are projected to reduce Australia's economic output by about 2.8 per cent at 2030 and 5 per cent at 2050 relative to what would otherwise occur. If GDP is assumed to grow by an average 2.4 per cent a year to 2050 in the reference case (without climate change impacts), a 5 per cent reduction in GDP by 2050

fig E **changes in Australia's gross domestic product and gross state product** relative to the reference case



box 2 other projections of climate change impacts on agricultural production

Schimmelpfennig et al. (1996), Rosenzweig and Tubiello (2007) and Darwin et al. (1995) have also examined the potential impact of climate change on agricultural production systems. Their analysis indicates that agricultural productivity declines are likely in the medium to long term as a result of climate change but that these declines will vary between regions. Schimmelpfennig et al. (1996) found that global production of all crops and livestock is projected to fall when carbon fertilisation effects are not considered (table 7). Darwin et al. (1995) found that world production of wheat is projected to increase but production of nongrain crops will fall as a result of future climate changes. Livestock production is also expected to increase. Rosenzweig and Tubiello (2007) project changes in average crop yields as a result of future climate changes of between a 1 per cent increase and a 5 per cent decrease depending on the climate scenario used.

7 climate change impact on world agricultural production

comparative static

	world production	
	without carbon fertilisation	with carbon fertilisation
	%	%
rice	-4.69	-0.35
wheat	-4.37	-0.54
other grains	-3.03	1.85
other crops	-2.02	-0.33
livestock	-2.31	0.07
processed agriculture	-3.33	-0.15

Source: Schimmelpfennig et al. (1996).

(from climate change) would convert to a reduction in average annual growth of 0.1 percentage points, to 2.3 per cent a year. For comparison, it is estimated that the 2002-03 and 2006-07 droughts reduced Australia's economic growth by about 1.0 and 0.75 percentage points respectively from what would otherwise have been achieved in the short term (Penm 2003; Penm and Glyde 2007). It is important to recognise that the impacts of drought tend to be short term. Whereas, climate change impacts will occur over the long term with the potential for cumulative effects and stepwise changes. The projected decline in gross state product in Queensland, the Northern Territory, South Australia and Western Australia are estimated to be greater than in the other states. This reflects not only the extent of climate change impacts on particular regions but also the relative size and structure of agriculture in different regions.

adaptation and mitigation: reducing the impacts of climate change

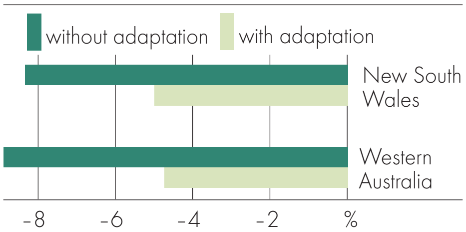
adaptation

It is important to recognise that adaptation to the impacts of climate change, including through better farm management practices, diversification of crop varieties, shifting cropping seasons, changing livestock breeds and improved farming technologies, can potentially reduce the magnitude of the losses in farm output from climate change (Heyhoe et al. 2007).

Historically, Australia's agriculture sector has adjusted and adapted continuously to external drivers, such as changes in the natural resource base, including climate variability. Such adaptation has been achieved predominantly through productivity improvements induced by technological changes, changes to farm management practices and more market oriented domestic policy reforms.

Following Heyhoe et al. (2007), the potential impact of on-farm technological adaptation measures in the wheat industry in New South Wales and Western Australia is assessed in an illustrative case study. The illustrative analysis is based on a relatively conservative assumption that a range of on-farm planned adaptation measures would reduce the decline in agricultural productivity as a result of climate change by 0.08–0.09

fig F **change in wheat production at 2030**
relative to the reference case



per cent a year (Heyhoe et al. 2007). For comparison, average productivity growth in broadacre agriculture in Australia over the past several decades has averaged around 2 per cent a year. No mitigation measures are assumed in this analysis.

The results of the illustrative analysis with assumed adaptation measures are shown in figure F. As expected, the adverse impacts of climate change on wheat production in New South Wales and Western Australia are reduced considerably as a result of the implementation of planned adaptation measures. For example, the impact of climate change on wheat production in New South Wales and Western Australia changes from falls of 8.4 per cent and 8.9 per cent respectively, relative to the reference case, at 2030 to losses of 5.0 per cent and 4.8 per cent respectively relative to the reference case when adaptation measures are put in place.

mitigation

Reducing global greenhouse gas emissions can moderate potential changes in climate and associated economic impacts. In Australia, emissions from agriculture account for about 17 per cent of total emissions (NGGI 2007). Given this contribution, reducing emissions in agriculture will be important for achieving long term domestic emission targets.

The introduction of lower emission production processes and changes in management practices in agriculture are vital for achieving reductions in emissions and allowing continued growth in industry output. Some mitigation options in agriculture, such as converting to minimum tillage, increasing the feed efficiency of livestock and changing fertiliser applications, can provide both cost savings and emission reductions. However, there may be a number of information or upfront cost barriers that need to be overcome to achieve widespread uptake.

Including agriculture in an emissions trading scheme will also reduce the total cost of abatement in the Australian economy and will also reduce the burden on other sectors of meeting an emissions target. The efficient level of mitigation in the agriculture sector will be influenced by the relative costs and benefits of both mitigation and adaptation. Much research is needed to better understand the opportunities and costs of mitigation in Australian agriculture (Gunasekera et al. 2007).

concluding comments

The illustrative scenario examined in this article demonstrates how future changes in climate may affect the Australian and global economies through impacts on productivity in agricultural and nonagricultural sectors. Impacts are projected to be felt both directly through reduced agricultural production and indirectly through a slowdown in overall economic activity. The economic impacts of climate change are projected to be considerable and unevenly distributed around the world, with developing countries suffering the most. Australia is also projected to be one of the most adversely affected developed regions given the importance of agriculture in its economy.

Based on the illustrative analysis discussed in this article, global production of several major agricultural commodities are projected to fall relative to what would otherwise be the case owing to future changes in climate. Production and exports of key Australian agricultural commodities are also projected to decline because of future changes in climate. Several policy implications that can be drawn from the illustrative scenario analysis are worth highlighting.

First, measures to mitigate greenhouse gas emissions domestically and globally will be a key to lessening the projected adverse impacts of climate change, including those affecting the agriculture sector. A portfolio of measures including market based policy instruments and adoption of cleaner and more energy efficient technologies will be needed across many parts of the world to reduce greenhouse gas emissions and, at the same time, achieve continuing economic growth and development. In Australia, the inclusion of agriculture in an emissions trading scheme will provide incentives to mitigate emissions from agriculture and opportunities for carbon sequestration, particularly in forestry. Mitigation measures, including those relating to emissions from enteric fermentation in livestock and from livestock waste, minimum tillage to reduce fossil fuel use and soil carbon emissions and better fertiliser management, will be required in agriculture to make a significant contribution to the reduction of greenhouse gas emissions. Reducing emissions from agriculture in Australia could be particularly important in meeting a long term domestic emissions target given that agriculture currently accounts for about 17 per cent of Australia's greenhouse gas emissions (NGGI 2007).

Second, another important way to respond to climate change is to adapt to the changes. Adaptation measures provide opportunities to manage risks and adjust economic activity to reduce vulnerability and improve business certainty in key sectors such as agriculture (COAG 2007). Planned adaptation generally involves enhancing adaptive capacity by developing new technologies and processes. For example, the development of cropping systems that are more efficient in water use and have high tolerance and resilience to pests and diseases and to salinity could be important. Increased research and development in such technologies is necessary for the agriculture sector to cost effectively adapt to changing climatic conditions in the medium to long term.

Third, there is a continuing need for the agriculture sector to improve productivity to cope with the potential pressures emerging from climate change and any associated policy responses. In this context, there is a need for appropriate policies designed to encourage rather than impede structural adjustment in vulnerable areas in the agriculture sector, including already marginal farming enterprises.

Finally, to maintain and enhance the productivity and international competitiveness of the agriculture sector, further research and development is required in both adaptation and mitigation technologies, with a key role to be played by both private and public sectors.

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