



Modelling the Economy-Wide Marginal Impacts Due to Climate Change in Australian Agriculture

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Modelling the economy-wide marginal impacts due to climate change in Australian agriculture

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Abstract

The decade from 2011 to 2020 started with the tail end of one of the wettest two year periods observed in eastern Australia and ended with recovery from the hottest and driest year ever recorded. An increasing prevalence of extremes is consistent with expectations concerning climate change.

This study uses observed rainfall and temperature anomalies to infer farm productivity levels by region. Productivity shocks are run year-by-year in the multi-regional VU-TERM model. The three scenarios of the study include a decade reflecting 2011 to 2020 seasons, a “2030” scenario in which farm productivity falls by 10% relative to the first scenario in five of the 10 seasons and a “2050” scenario in which, in the corresponding years, farm productivity falls 20%.

The welfare impact of the first scenario relative to a baseline without year-on-year seasonal variations is minus \$35 billion in net present value terms. The welfare impact in the second scenario is minus \$46 billion and minus \$59 billion in the third scenario.

Welfare losses are alleviated to a small extent by resource movements. In particular, in years in which drought induces collapses in productivity, livestock production switches from grazing to fodder inputs. The study assumes that Outback Queensland consists of rangeland production in which a switch to fodder is not feasible. The region’s income losses in drought are worse than elsewhere. Lack of input flexibility contributes to the region’s losses.

JEL classification: C68; Q54; R11; R15

Keywords: regional drought impacts; climate change; welfare; adaptation

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Modelling the economy-wide marginal impacts due to climate change in Australian agriculture

1. Introduction

Evidence is mounting of climate change within Australia. The Bureau of Meteorology reports that the mean temperature nationally in the decade ending 2020 was 0.95C above average, and 0.33C above the previous decade. Since 2013, every year has been among the ten warmest ever recorded.¹ In the southwestern part of Western Australia, annual rainfall has declined by up to 20% since the early 1970s. This has resulted in streamflow declines of around 80%. The year 2019 was the hottest and driest ever recorded. Australia received global attention when bushfires razed 5.6 million hectares across the nation in the summer of 2019-20. Most of the fires occurred in relatively high rainfall areas along the Great Dividing Range and towards the coast in southeastern Australia. Unprecedented low soil moisture conditions resulted in unprecedented vulnerability to bushfires.²

The objective of this study is to concentrate on one dimension of climate change. The study is confined to regional impacts of climate on agricultural output using a dynamic, multi-regional CGE model.

2. VU-TERM modelling

VU-TERM is the CGE model used in this study. There are three climate scenarios. Actual mean rainfall and temperature recorded from 2016 to 2020, and from 2011 to 2015, provide the basis for the first run. Year 1 agricultural productivity reflects 2016 conditions, year 2 2017 conditions and so to year 5. Thereafter, year 6 reflects 2011 conditions, up to year 10 reflecting 2015 conditions (see appendix A).

The baseline against which we compare the deviations in model runs is relatively bland, consisting of “average” seasons with baseline productivity. Farmers prefer relatively “average” conditions but there is a tendency with climate change for extremes to occur more frequently. The decade ending 2019 provides a stark example, with the two-year period of 2010-2011 being among the wettest ever recorded over substantial parts of eastern Australia and 2018-2019 being the driest recorded over much of the southeastern quadrant of the continent. But even in the relatively high rainfall event of 2010-2011, when we might expect temperatures to be lower, temperatures were near the long-term average. In the 2018-2019 drought, mean temperatures were more than 1.5C degrees above the mean over most of the southeastern quadrant.

We can think of the first run as a stylized version of 2020 climatic conditions. In a second run, a stylized depiction of 2030, the years of drought have the same farm productivity levels as those of the first run. In the “2030” set, productivity levels are 10% worse than the first run in years 1, 5, 7, 9 and 10. Finally, in the “2050” set of runs, productivity levels in the same five years are 20% worse than in the first run, while keeping productivity levels the same as the first run in years 2, 3, 4, 6 and 8.

The productivity assumptions for the “2030” and “2050” runs may underestimate impacts due to rising temperatures. The objective of this study is not to work with the “most likely”

¹ See <http://www.bom.gov.au/climate/current/annual/aus/>

² See <http://www.bom.gov.au/water/landscape/#/sm/Relative/day/-28.37/130.43/4/Point////2019/12/31/>

scenario, but rather to provide a framework to quantify the economic impacts and responses to climate change. Refined runs may follow in future studies.

The advantages of this approach is that it includes greater regional detail and greater year-by-year texture than past CGE modelling efforts. Each of these matters. Inland farming regions appear to be more vulnerable than coastal regions to rising temperatures.³ The biggest impacts from climate change do not arise from changes in rainfall and temperatures averages, but from extremes. To illustrate, in 2019, the driest and hottest year ever in Australia, a flood hit Townsville and regions to west in late January, dumping 1400mm of rain on Townsville in around 10 days. This resulted in both a short-lived cessation of economic activity in the city plus longer term impacts on damaged housing, crops and infrastructure, none of which is modelled in this study. It was an extreme flood event in a time of drought.

Many previous modelling efforts have used adaptations of the multi-country, global GTAP model (Liu *et al.* (2016) is one example). GTAP has one important advantage over TERM-VU: it can estimate terms-of-trade impacts arising from changes in relative global scarcity. This implies that it is possible for a particular nation to suffer a decrease in farm output, yet more than offset that decrease via a terms-of-trade gain arising from global price increases for farm outputs. The VU-TERM results presented in this study assume that there is no ongoing outward export demand shifts for farm produce arising from worsening global relative scarcity.

Future studies may include modifications to GTAP variants or add biophysical accounts to VU-TERM for variables including soil moisture, groundwater levels and river flows. Studies using VU-TERM may include more detailed inputs concerning climate variation, and also use modelled relative price impacts from GTAP as exogenous export demand or import supply shifts.

3. The first scenario – a “2020” decade

The first scenario models two phases in the “2020” decade. First, years 1 to 5 (i.e, 2016 to 2020) use observed regional annual rainfall and temperature differences from average to infer farm productivity levels for each region. An appendix shows the rainfall and temperatures and the farm productivity levels for each year based on these. Year 6 to 10 are based on historical annual rainfall and temperature differences for 2011 to 2015.

In years of drought, productivity falls sharply relative to base in agricultural sectors in farm-affected regions.

GDP on the income side is a function of primary factors (capital K and employment L) and underlying technology ($1/A$):

$$GDP = f(K, L, \frac{1}{A}) \quad (1)$$

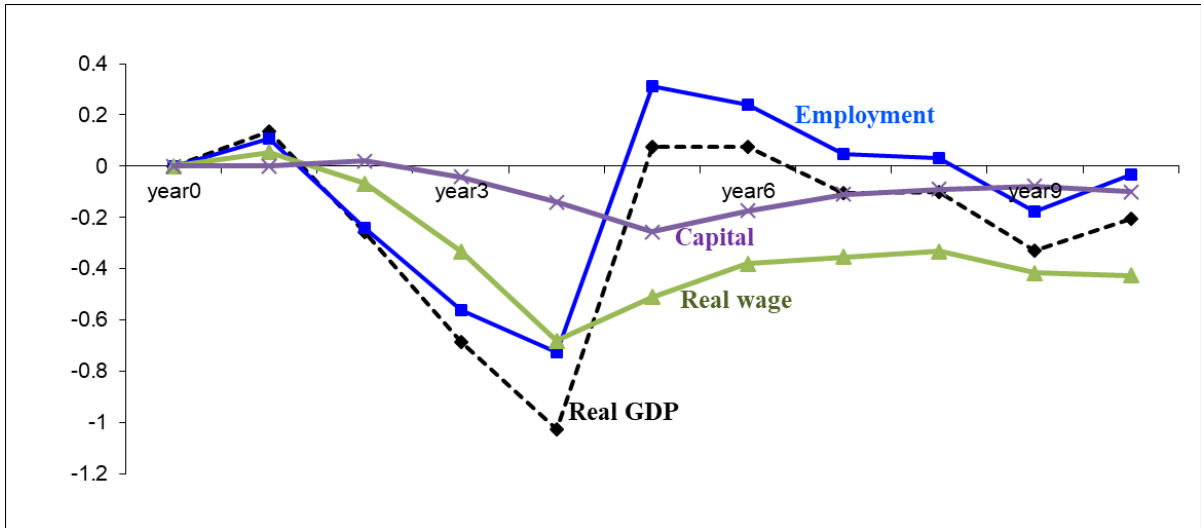
Although agriculture accounts for little more than 2% of GDP, wide variations in seasonal conditions can make significant contributions to national income fluctuations. This is evident in figure 1, in which real GDP falls to 1% below base in year 4, which reflects the historical

³ An exception is in tropical region, in which new agricultural developments tend to be away from the coast, due to expectation of more severe cyclones in the future.

seasonal inputs to 2019-20 (i.e., 2019, the hottest and driest year on record in Australia). Some of the decline in capital, which falls to as much as 0.2% below base, arises from culled livestock in drought years, and some from depressed investment in drought years (figure 2).

Figure 1: Real GDP, national, income side; labour market

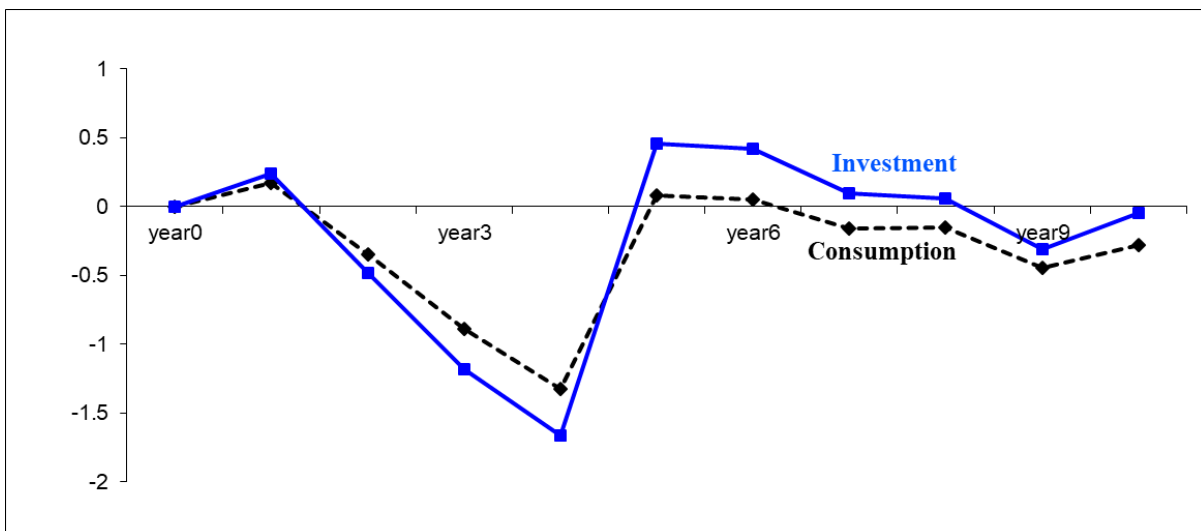
(% deviation from base)



Drought-induced productivity losses weaken the labour market. Figure 1 shows that within the theory of the model, productivity losses depress both real wages and employment relative to base.⁴ In year 5, which is a recovery year, aggregate investment rises above base, and employment rises with it (figures 1 and 2).

Figure 2: National aggregate consumption and investment

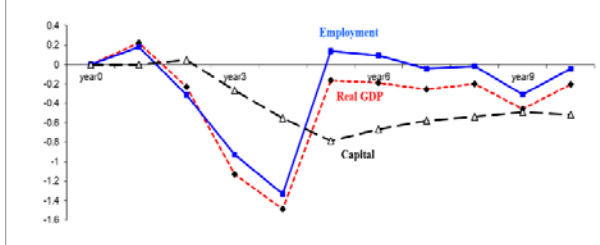
(% deviation from base)



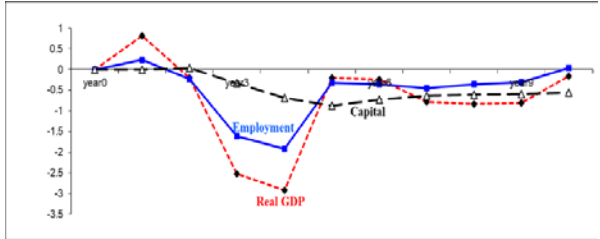
⁴ Prior to COVID-19, wages growth had been slow for a number of years. Drought contributed to diminishing real wages growth.

Figure 3: Income-side real GDP at the regional level, “2020” scenario
 (% deviation from base)

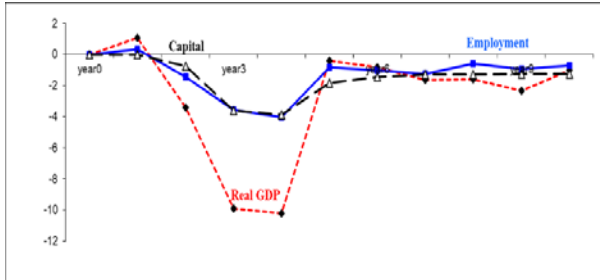
Capital Region, NSW



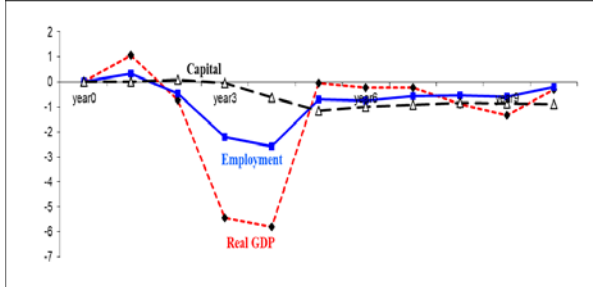
Central West, NSW



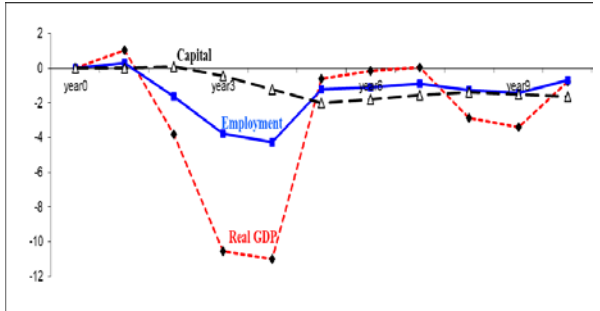
Far West – Orana, NSW



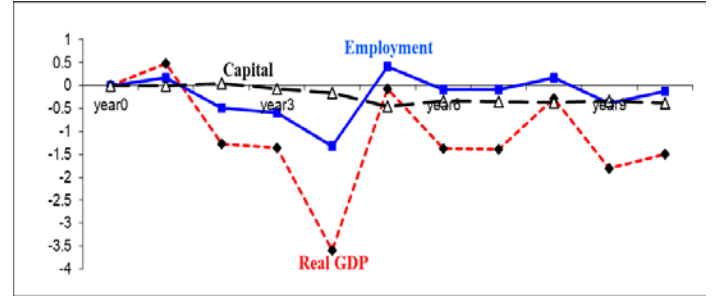
Riverina—Murray NSW



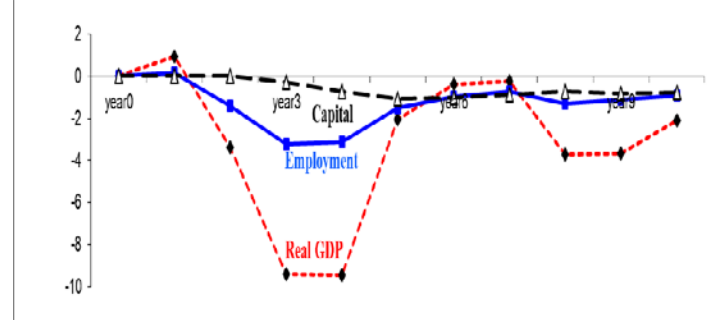
New England – North West – Grafton



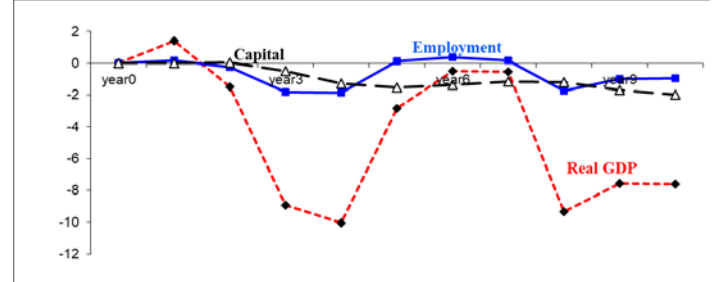
Northern and Central Victoria



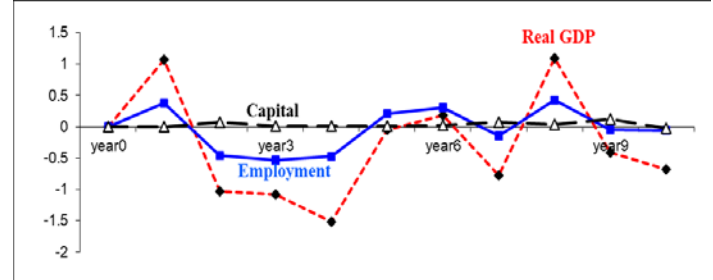
Darling Downs-Maranoa-Granite Belt, Qld



Outback Queensland



Eyre Peninsula, Mallee and Outback, SA



Wheatbelt, WA

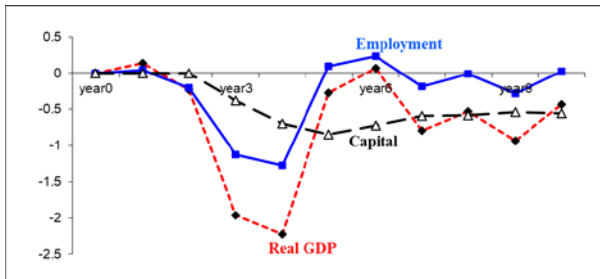


**Figure 4: Income-side real GDP at the regional level, “2030” scenario
(% deviation from base)**

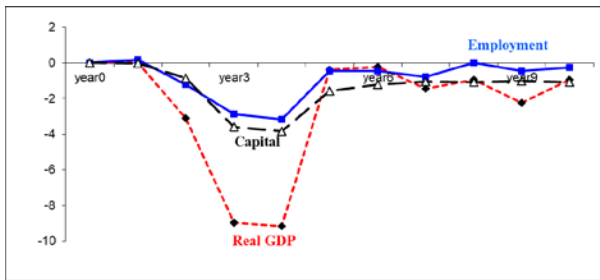
Capital Region, NSW



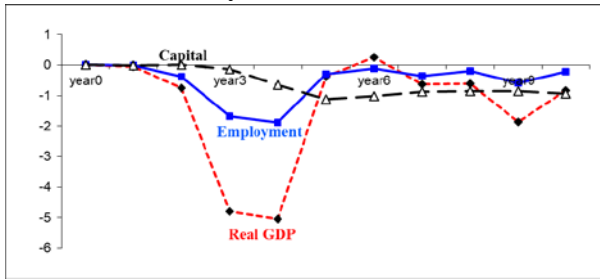
Central West, NSW



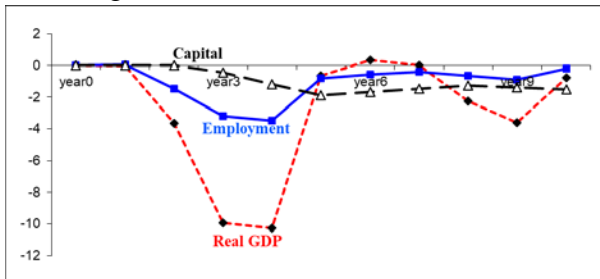
Far West – Orana, NSW



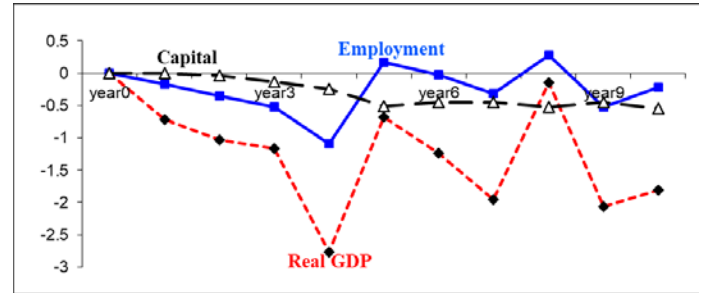
Riverina—Murray NSW



New England – North West – Grafton



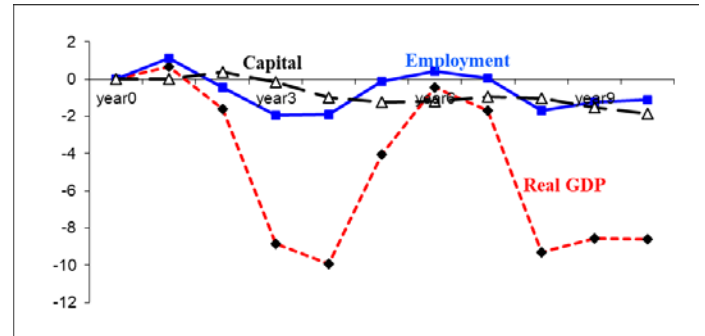
Northern and Central Victoria



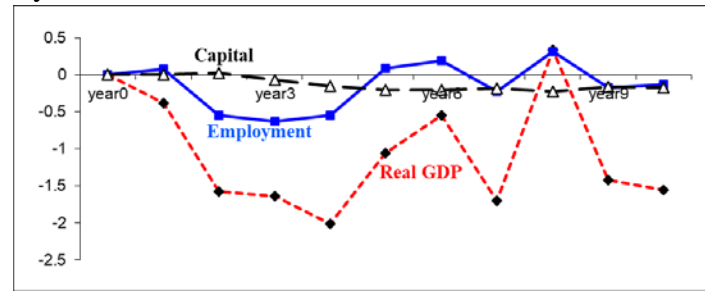
Darling Downs-Maranoa-Granite Belt, Qld



Outback Queensland



Eyre Peninsula, Mallee and Outback, SA



Wheatbelt, WA

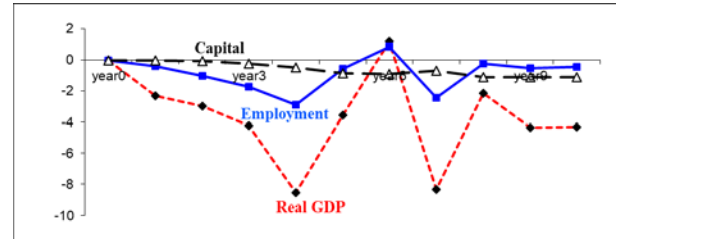
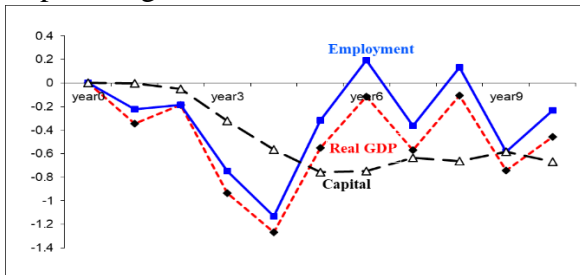
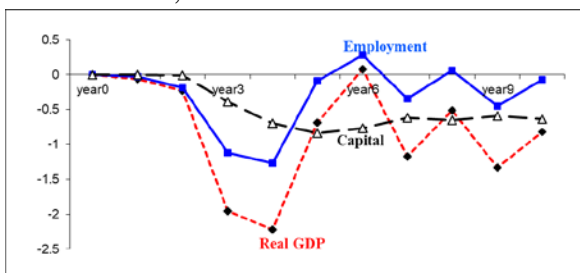


Figure 5: Income-side real GDP at the regional level, “2050” scenario
 (% deviation from base)

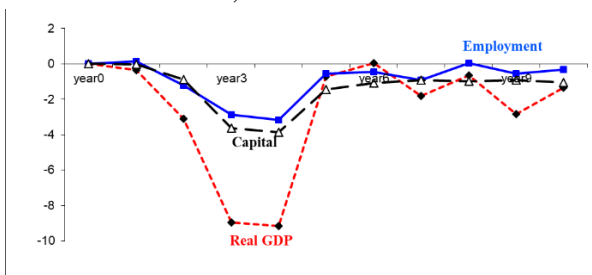
Capital Region, NSW



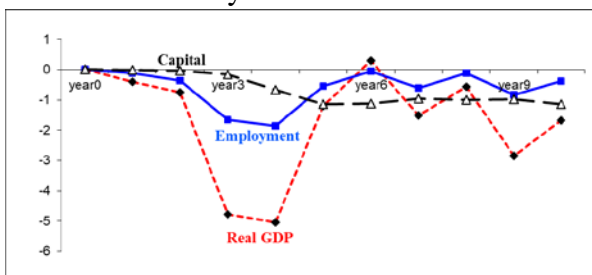
Central West, NSW



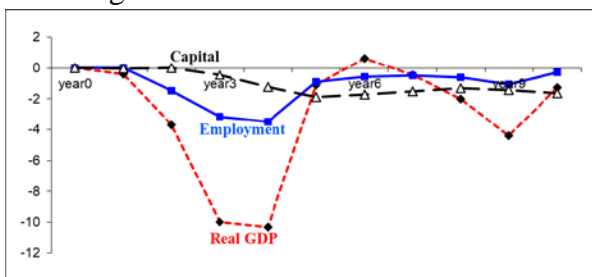
Far West – Orana, NSW



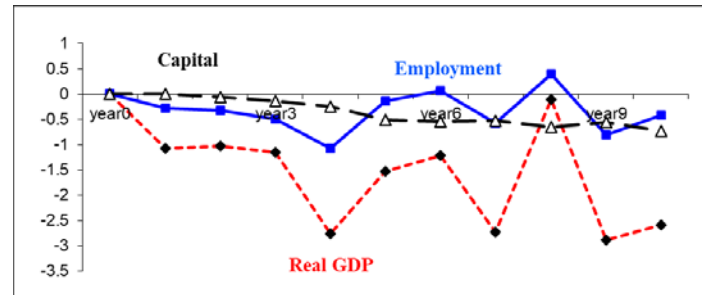
Riverina—Murray NSW



New England – North West – Grafton



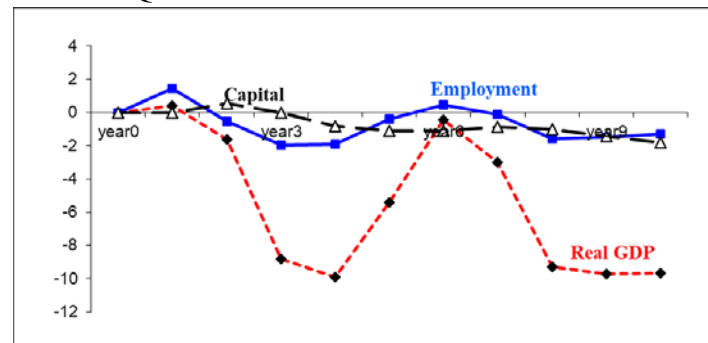
Northern and Central Victoria



Darling Downs-Maranoa-Granite Belt, Qld



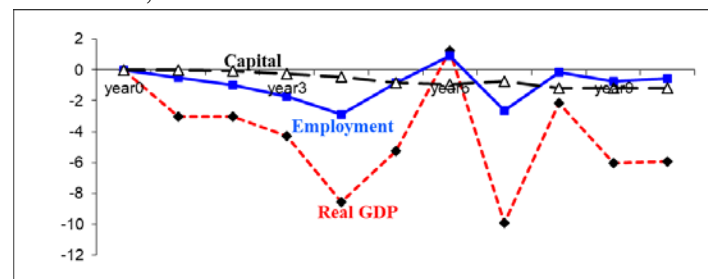
Outback Queensland



Eyre Peninsula, Mallee and Outback, SA



Wheatbelt, WA



The impacts in relatively agriculture-intensive regions are proportionally much greater than those at the national level. Figure A2 shows agriculture's share of GDP for each in the model. In Far West-Orana, New England-North West-Grafton, Darling Downs-Maranoa-Granite Belt and Outback Queensland, there are prolonged periods in which real GDP falls more than 8% below base in the "2020" scenario. In figure 1 and figures 3 to 5, drought-induced technological deterioration is evident. Real GDP is a macro measure of output. In years 3 and 4, the percentage fall in real GDP is larger than the percentage fall in labour or utilized capital at the national level and in many of the regions shown. From equation (1), technological deterioration explains the gap between the percentage deviation in factor inputs and real GDP. In any drought-affected region, real GDP will fall further than the share-weighted sum of primary factors.

Employment nationally falls to more than 0.7% or more than 70,000 jobs below base in year 4. By assumption, real wages adjust sluggishly at the regional level. In circumstances of severe regional downturns, we expect real wages adjustment to be limited: any workers who are relatively mobile and even some who in normal circumstances are less mobile may leave a region. In addition, participation rates may fall temporarily in drought. To avoid unrealistic downward wages adjustment, exogenous temporary downward labour supply shifts are imposed in a number of regions in year 4. Consequently, in the "2020" run, no regional real wages fall more than 2% below base in any year. In Far West-Orana and New England-North West –Grafton, employment is around 4% below base in year 4, reflecting an exogenous downward labour supply shift in addition to the endogenous impacts of prolonged drought.

4. The "2030" and "2050" scenarios

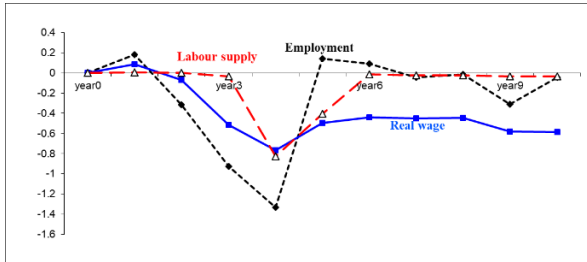
The assumption underlying the "2030" scenario is that relatively normal years are hotter and therefore effective rainfall is less than in corresponding years of the "2020" scenario. The "2050" scenario takes this a step further, with larger productivity declines, reflecting higher temperatures and lower effective rainfall.

The two scenarios depict weaker recovery years and larger income losses than the "2020" scenario in years 1, 5, 7, 9 and 10.

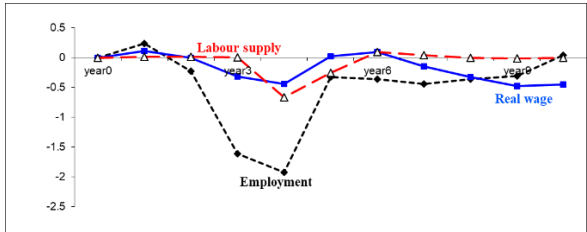
Figure 4 shows the regional income-side GDP impacts for the "2030" scenario and figure 5 the corresponding "2050" impacts. Among the impacts, employment is slightly lower in the "2030" and "2050" scenarios than the "2020" scenario. If the downward labour supply shifts were applied to later years in some regions in the "2050" scenario, employment impacts would be larger. For example, in Outback Queensland, in which years 9 and 10 turn from moderate drought in the "2020" scenario to severe drought in the "2050" run, a labour supply shift would lessen the real wage drop and worsen the employment outcome, which is 1.3% below base in year 10 (figure 7). The theory of the model allows for an endogenous decrease in labour supply over time: it falls to 0.6% below base in year 10, not sufficient to prevent real wages from dropping more than 2% below base in Outback Queensland in that year.

Figure 6: Labour markets, “2020” scenario
 (% deviation from base)

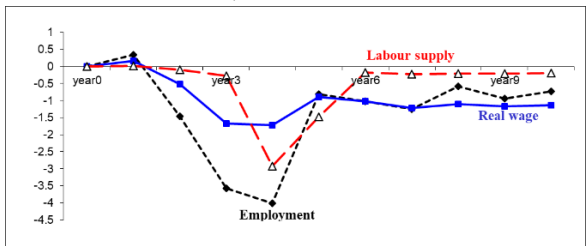
Capital Region, NSW



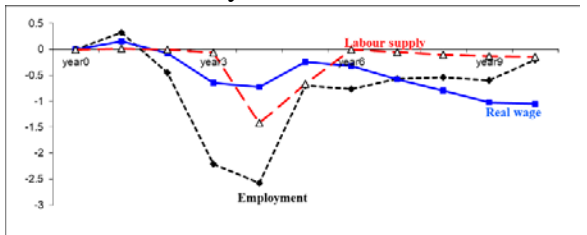
Central West, NSW



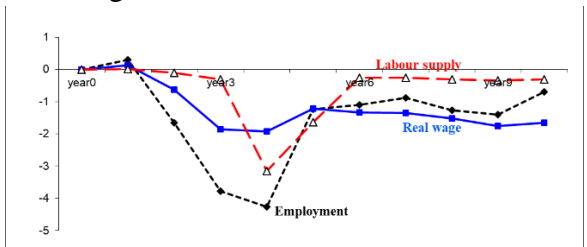
Far West – Orana, NSW



Riverina—Murray NSW



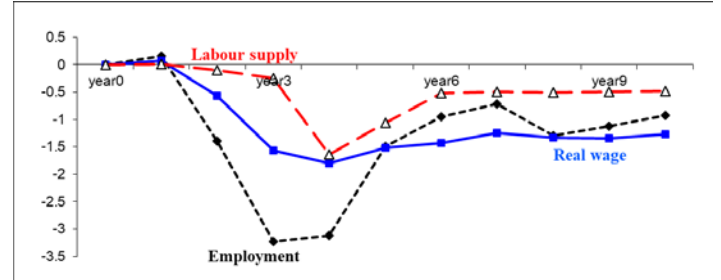
New England – North West – Grafton



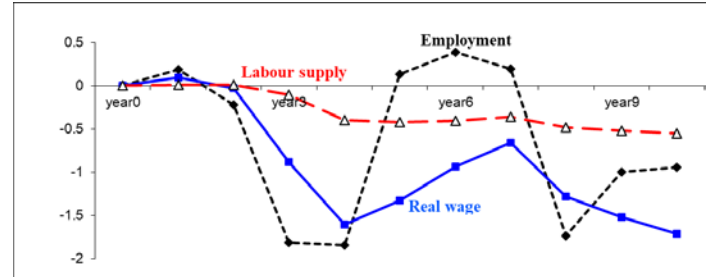
Northern and Central Victoria



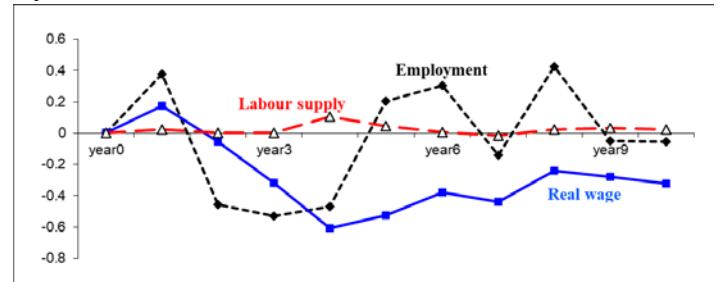
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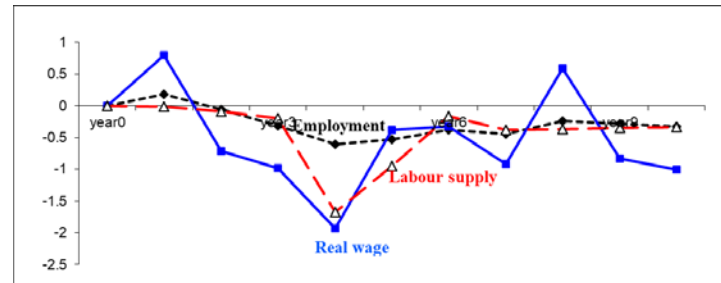
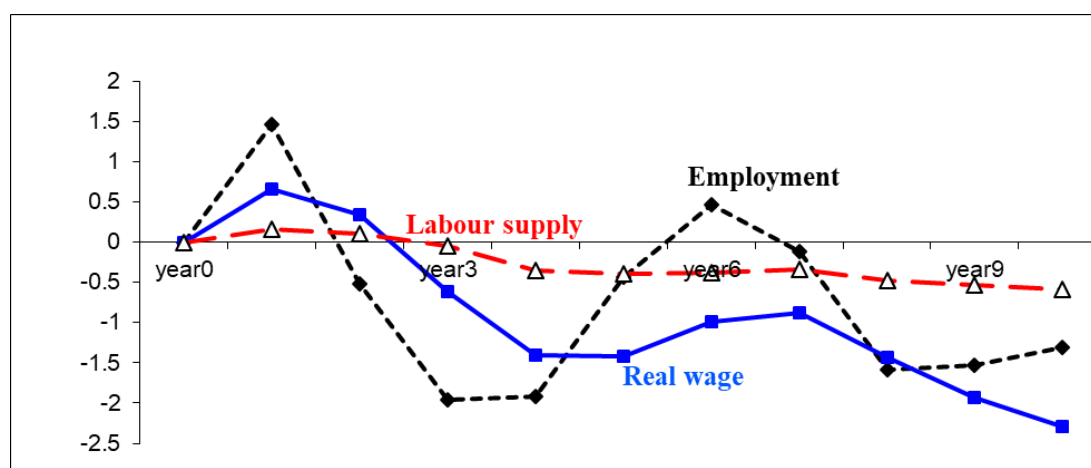


Figure 7: Labour market, Outback Queensland, “2050” scenario

5. Industry composition changes

In regions other than Outback Queensland, as productivity falls due to drought, there is a switch from pasture grazing to fodder inputs. The theory of VU-TERM includes substitutability between land and fodder (*HayCerealFod*) in livestock production. A key assumption is that fodder produced in one year may be used in another, thereby providing a means of managing seasonal risk. We usually assume that intermediate inputs are used in the same period as they are produced. *HayCerealFod* productivity shocks are not imposed in the “2020” run, to reflect that fodder produced in good years may be used in drought years. In rangeland production in Outback Queensland, we assume that this is not possible and that output (i.e., herd numbers) must diminish during prolonged dry spells.

In VU-TERM, in the drought years 2 to 4, beef cattle output in New England – North West – Grafton rises relative to base (table 1). This reflects the assumption that fodder (including feedlotting) inputs substitute for land inputs throughout the region.⁵ Beef cattle output collapses in Outback Queensland due to an inability, by assumption, to switch to fodder in the region.⁶ The modelled outcome therefore is that even though land productivity in beef cattle production collapses in New England – North West – Grafton, there is an increase in output. This reflects a switch from Outback Queensland to the northern NSW region in production, due to a relative gain in cost competitiveness in the NSW region. A lower degree of substitutability between fodder and land in the region would lessen the switch.

In the “2030” and “2050” scenarios, in which productivity losses worsen in Outback Queensland, the switch in output to the NSW region enlarges. This switch is not specific to New England – North West – Grafton: it applies to all beef cattle producing regions other than Outback Queensland. By assumption, each of these has substitutability between land and fodder inputs in livestock production.

⁵ . During the 2017-2019 drought, herd numbers across NSW declined, reflecting severe drought. The share of cattle in feed-lotting rose in response to drought. Some farmers particularly on the Liverpool Plains, which historically is not prone to drought, did not have fodder on hand. They faced prohibitive input costs if they sought to maintain herd numbers.

⁶ To mimic lack of substitutability, a total factor productivity shock was applied to livestock in the Queensland Outback region instead of a land productivity shock.

Table 1: Farm outputs
(% deviation from base)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
“2020”										
OthBrdAcrCrp	6.2	-9.6	-21.0	-38.5	-0.9	-0.5	-7.2	-5.2	-13.2	-10.3
Horticulture	-0.8	-3.7	-7.4	-15.0	-1.0	-3.1	-4.4	0.2	-5.3	-5.6
Sheep	0.4	-0.4	-2.7	-3.8	-0.5	0.0	0.0	-1.4	-1.6	-1.0
BeefCattle	0.1	-0.3	-3.5	-3.8	-0.3	0.2	0.2	-2.8	-2.1	-1.9
Wheat	17.8	-15.2	-40.0	-48.1	-8.6	0.4	-23.8	-9.9	-21.2	-18.9
Cotton	0.9	-10.8	-35.4	-39.3	-2.5	1.5	-2.1	-17.4	-19.1	-8.4
HayCerealFod	0.5	-0.6	-1.4	-2.3	-0.3	-0.3	-1.0	0.0	-0.8	-0.5
DairyCattle	0.2	-0.4	-1.5	-3.3	-1.1	-1.0	-1.2	-0.9	-1.7	-1.6
OthLivstock	0.3	-0.4	-1.7	-2.4	-0.2	0.1	-0.1	-1.1	-1.3	-1.0
<i>BeefCattle (regional):</i>										
<i>OutbackQld</i>	9.5	-9.9	-53.9	-55.0	-14.6	4.1	4.6	-55.0	-45.3	-45.8
<i>NewEngNWGrft</i>	-1.5	2.0	6.4	4.2	1.8	0.1	0.0	7.7	6.6	7.7
“2030”										
OthBrdAcrCrp	-1.7	-9.4	-20.9	-38.4	-8.0	-0.6	-14.0	-5.2	-19.9	-16.8
Horticulture	-10.7	-4.7	-8.4	-16.0	-10.1	-3.9	-13.5	-0.6	-14.3	-14.5
Sheep	-7.4	-0.8	-3.1	-4.1	-1.8	-0.4	-1.4	-1.7	-3.0	-2.4
BeefCattle	-2.8	-0.4	-3.5	-3.8	-1.1	0.1	-0.5	-3.0	-3.2	-2.9
Wheat	6.5	-15.2	-40.1	-48.1	-16.9	0.5	-30.5	-9.8	-28.3	-25.9
Cotton	-4.5	-10.8	-35.4	-39.4	-6.6	1.4	-5.9	-17.4	-24.3	-13.0
HayCerealFod	-3.5	-0.1	-0.9	-2.0	-4.8	0.3	-5.0	0.7	-4.8	-4.2
DairyCattle	0.1	-0.7	-1.8	-3.5	-2.1	-1.5	-2.4	-1.5	-3.1	-3.0
OthLivstock	-1.5	-0.4	-1.7	-2.4	-1.0	0.0	-0.9	-1.2	-2.1	-1.8
<i>BeefCattle (regional)</i>										
<i>OutbackQld</i>	6.5	-9.5	-53.6	-54.6	-23.2	4.6	-5.3	-54.8	-51.5	-52.0
<i>NewEngNWGrft</i>	-5.0	2.3	6.8	4.5	2.5	0.3	0.9	7.9	6.9	8.1
“2050”										
OthBrdAcrCrp	-4.3	-9.4	-20.8	-38.4	-16.1	-0.6	-21.6	-5.2	-27.4	-24.1
Horticulture	-13.8	-5.1	-8.7	-16.4	-20.0	-4.4	-23.2	-1.1	-24.1	-24.4
Sheep	-9.8	-0.9	-3.2	-4.3	-3.2	-0.5	-2.7	-1.8	-4.4	-3.6
BeefCattle	-3.8	-0.4	-3.5	-3.8	-2.0	0.0	-1.2	-3.0	-4.3	-4.0
Wheat	3.0	-15.2	-40.1	-48.1	-25.5	0.6	-37.3	-9.6	-35.5	-33.1
Cotton	-6.3	-10.9	-35.4	-39.4	-11.5	1.3	-10.4	-17.4	-30.1	-18.2
HayCerealFod	-4.9	0.1	-0.8	-1.8	-10.4	0.9	-10.0	1.5	-9.5	-8.6
DairyCattle	0.1	-0.8	-1.8	-3.6	-3.0	-1.8	-3.5	-2.0	-4.5	-4.5
OthLivstock	-2.2	-0.5	-1.8	-2.4	-1.8	0.0	-1.7	-1.2	-2.9	-2.6
<i>BeefCattle (regional)</i>										
<i>OutbackQld</i>	5.4	-9.3	-53.5	-54.5	-32.5	4.6	-16.1	-54.8	-57.9	-58.5
<i>NewEngNWGrft</i>	-6.2	2.4	6.9	4.6	3.1	0.4	1.7	8.1	7.0	8.2

6. Welfare impacts

The calculation of the deviation in welfare ($dWELF$) in VU-TERM is given by

$$dWELF = \sum_d \sum_t \frac{dCON(d, t) + dGOV(d, t)}{(1+r)^t} - \frac{dNFL(z)}{(1+r)^z} + \frac{dKstock(z)}{(1+r)^z}$$

where $dCON$ and $dGOV$ are the deviations in real household and government spending in region d and year t ;

$dNFL$ is the deviation in real net foreign liabilities in the final year (z) of the simulation;
 $dKstock$ is the deviation in value of capital stock in the final year (z) of the simulation;
 and
 r is the discount rate.

In the “2020” run, based on rainfall and temperature anomalies of 2011-2020, the net present value of the welfare loss is \$35 billion. In the “2030” run, this worsens to \$46 billion. In the “2050” run, the losses are \$59 billion. Once these are converted to annuities, the losses are not huge. For example, at the 2.5% discount rate (r) used in the calculation, a net present value of minus \$59 billion equates to an annuity of minus \$1.5 billion or around \$60 per capita. However, the losses are concentrated in agricultural regions, some of which experience recession for a number of years. Outback Queensland is the most vulnerable, given that livestock production accounts for a relatively large share of regional GDP and that production is relatively inflexible.

The next section discusses other losses that might arise from climate change not modelled here.

7. Conclusion and research possibilities

This study uses a decade of rainfall and temperature anomalies to model the impacts of climate change on agricultural regions. Both income losses and fluctuations in income are substantial in regions in which agriculture accounts for a relatively large share of the income base.

Risk-management practices such as the use of fodder in livestock production in drought years may alleviate some losses. Within a CGE model, it is possible to alter the theory to reflect different degrees of farm production flexibility. Wittwer and Griffith (2012) use TERM-H2O, which includes irrigation water accounts and allows for water trading and on-farm factor mobility between different outputs, to depict basin-specific flexibility. In the Murray-Riverina region, for example, farm inputs move away from annual towards perennial crops in drought years. The version of VU-TERM in this study does not include additional equations to reflect a degree of flexibility that may be possible in some irrigation regions.

Although potential drought losses are substantial in some regions, the economic risks arising from climate change extend beyond losses modelled here. For example, in tropical Queensland, more severe cyclones arising from climate change may result in an increase in damage to housing, infrastructure and crops. Flooding may halt local economic activity for a week or more, while inflicting damage on capital. VU-TERM modelling of the 2019-20 bushfires indicated that welfare losses exceed \$10 billion, even before counting losses in national parks and forests, and excluding any valuation of lost human lives. Bushfires also raise future insurance costs for households and business in bushfire-prone areas. Valuable coastal properties and amenities may be damaged by storms of rising severity associated with climate change. Health costs and labour productivity losses may worsen with climate change related increases in disease prevalence or bushfire smoke, as happened in NSW in 2019-20. Most of these impacts could be modelled using VU-TERM. Some studies have already been undertaken for clients using the model.

Finally, the choice of regions in a given scenario can be adapted to reflect particular interests. For example, in this study, Tasmania and the Northern Territory were combined to keep

analysis to a manageable number of regions. A particular study may focus on Tasmania or sub-state regions within Tasmania, which would require a different aggregation of the 334 regions of the master database.

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Appendix A: maps of historical rainfall and temperature variation and accompanying agricultural productivity levels

Figure A1: Regions of VU-TERM in this study*



*Rest of Australia (RoA) includes Tasmania. Tasmania’s rainfall and temperature anomalies determine the region’s productivity levels.

Figure A2: Agriculture as % of regional GDP

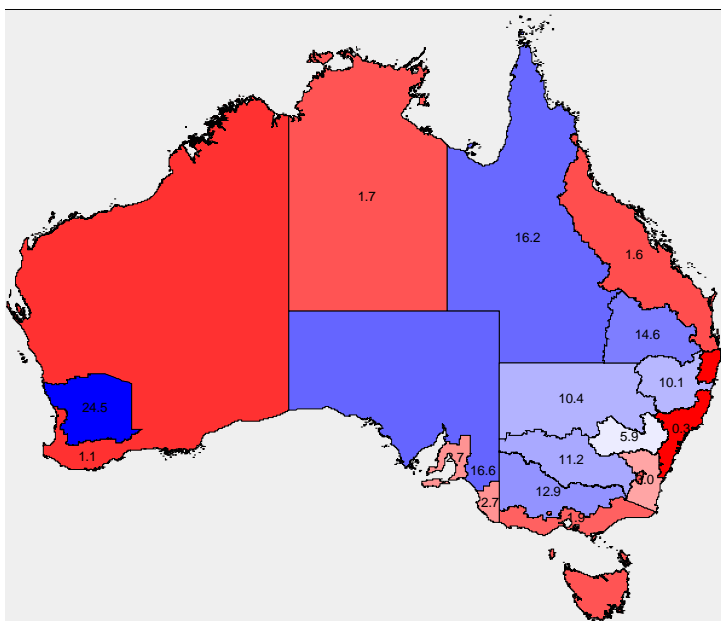
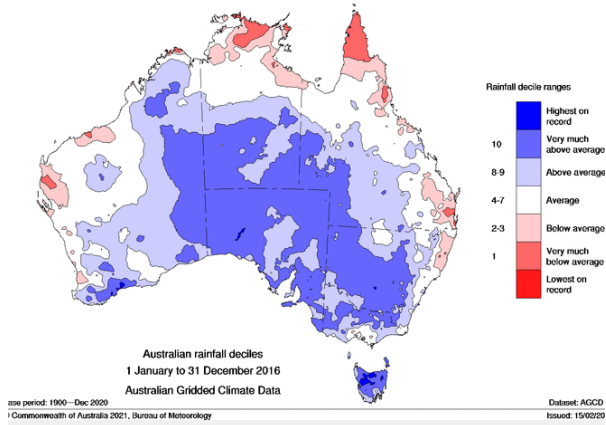
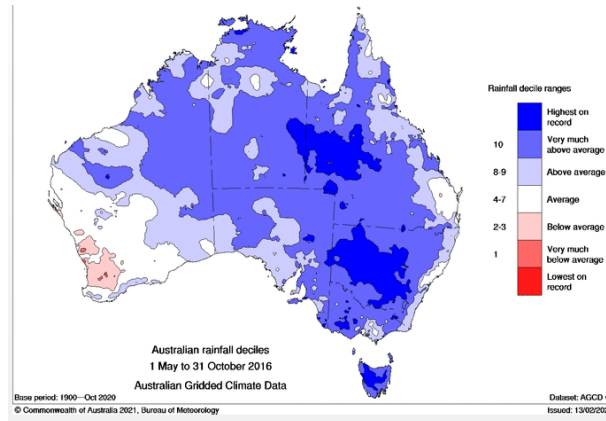


Figure A3: Rainfall & temperature anomalies and consequent farm productivity levels

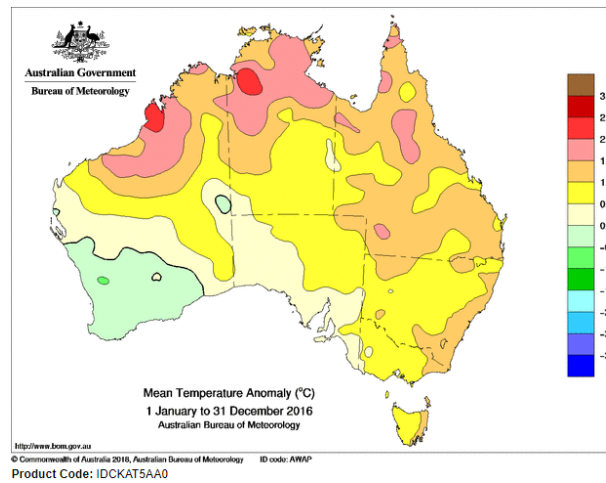
Year 1 (2016)



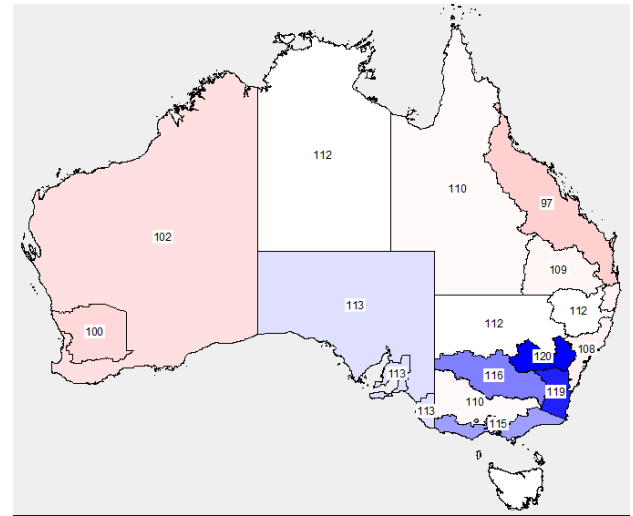
Winter rain year (2016):



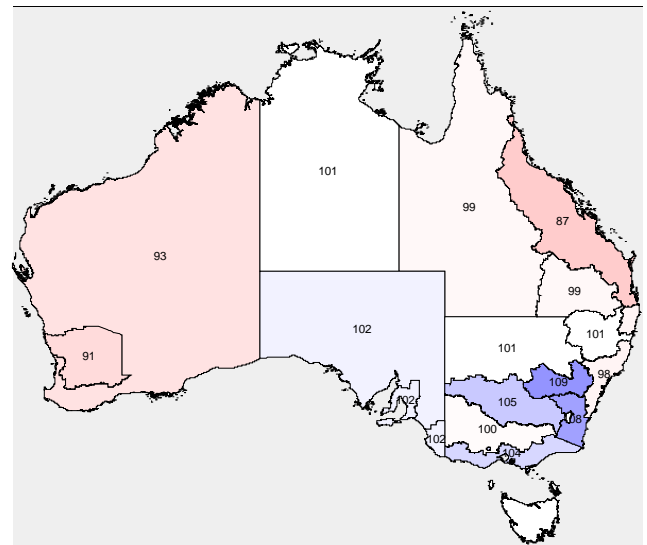
Mean temperature anomaly year 1:



Seasonal index year 1 "2020" = 2016-17



"2030" yr 1



"2050" yr 1

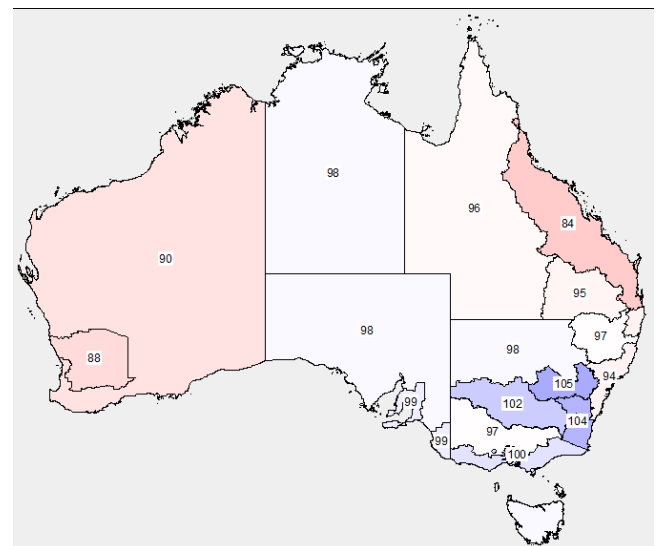
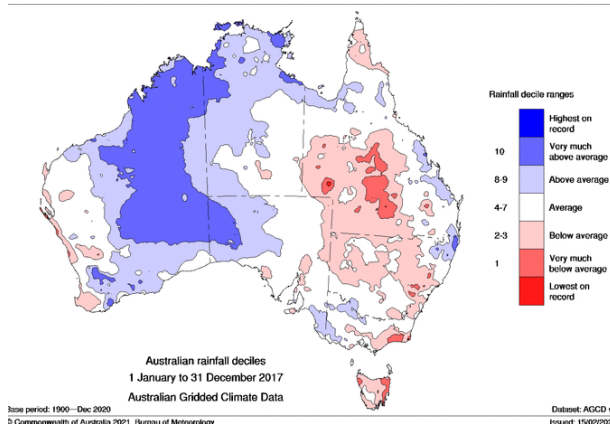
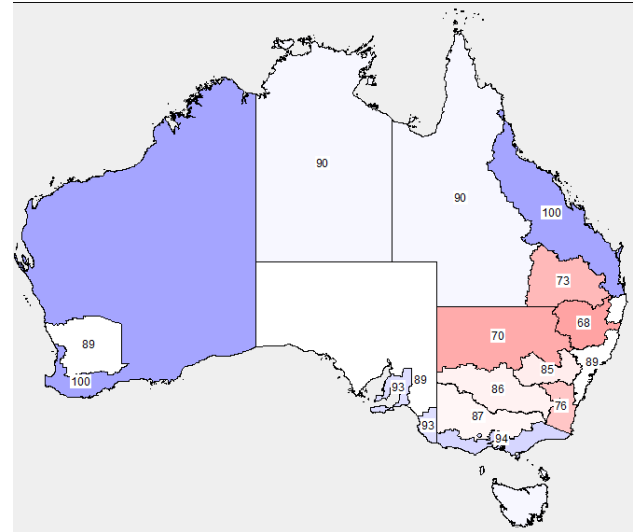


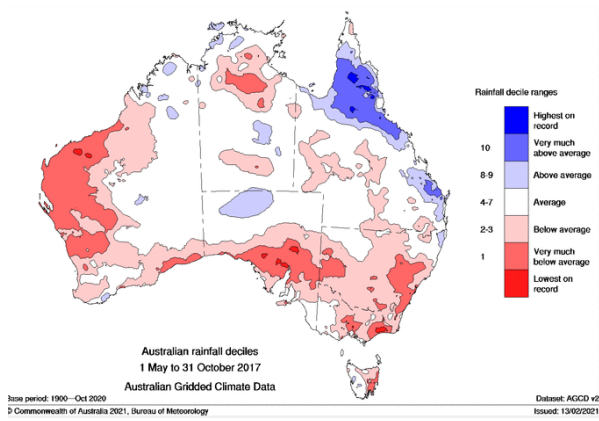
Figure A3 (cont.):



Seasonal index year 2 all runs= 2017-18



Winter rain year 2:



Mean temperature anomaly year 2:

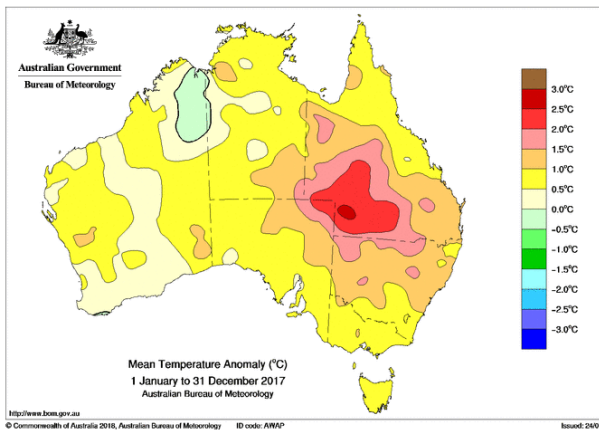
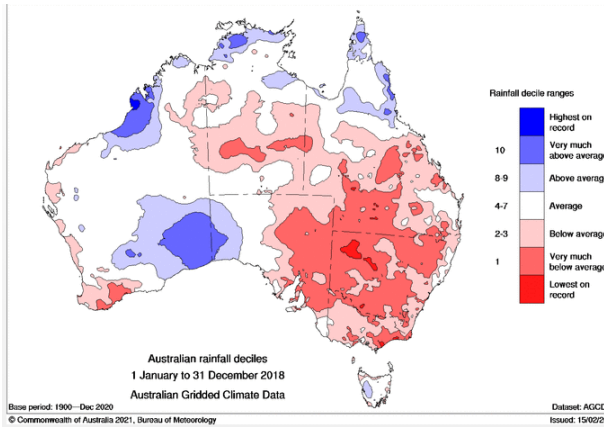
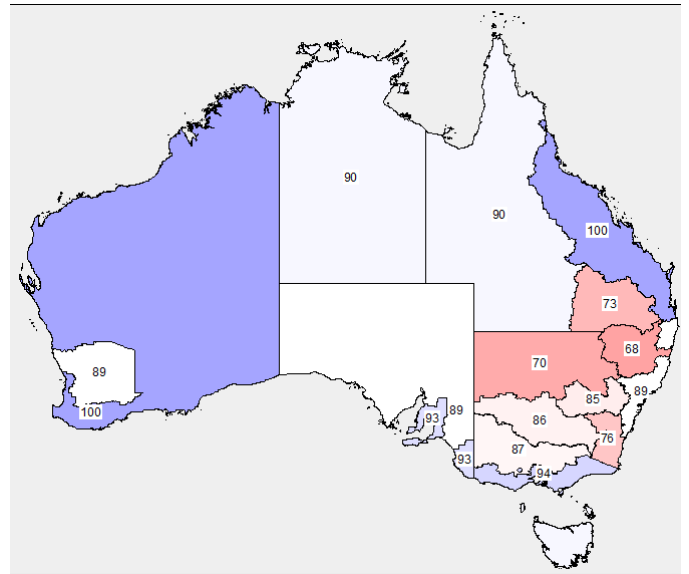


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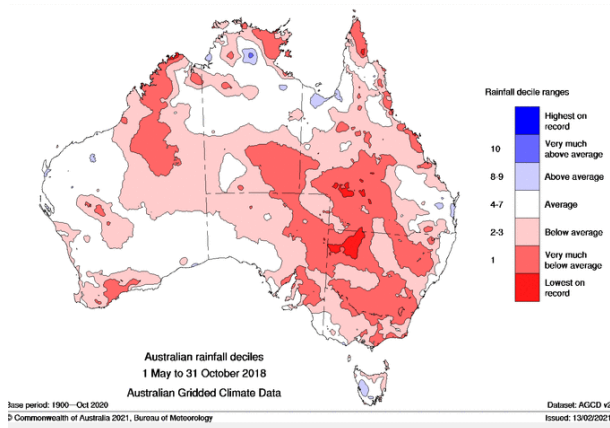
Year 3 (2018)



Seasonal index year 3 all runs= 2018-19



Winter rain year 3:



Mean temperature anomaly year 3:

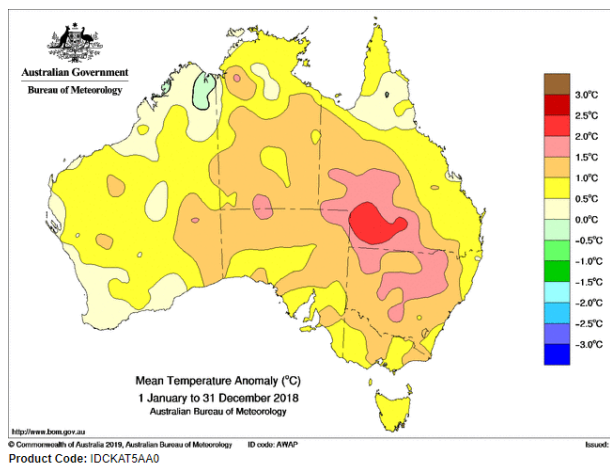
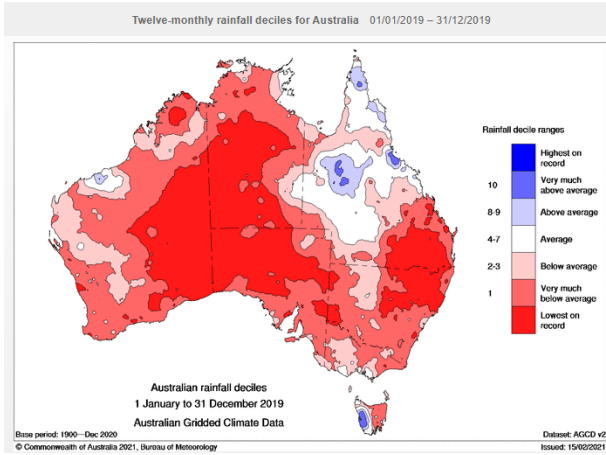
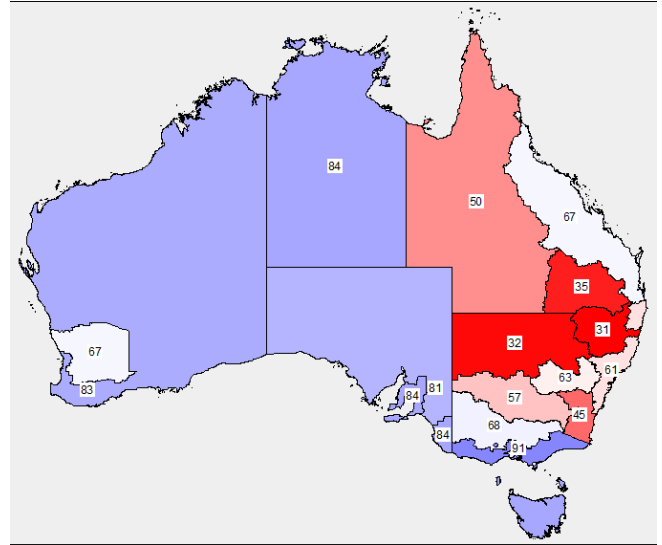


Figure A3 (cont.):

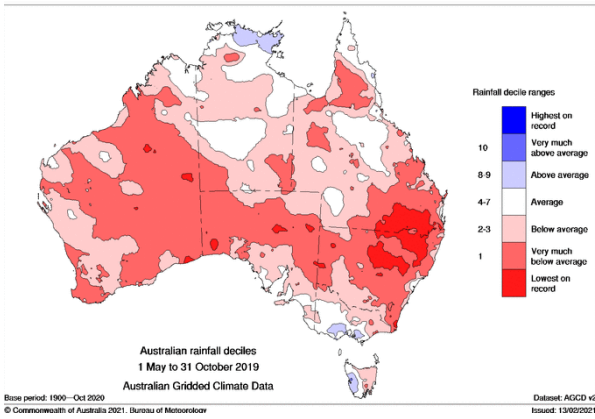
Year 4(2019)



Seasonal index year 4 all runs= 2019-20



Winter rain year 4:



Mean temperature anomaly year 4:

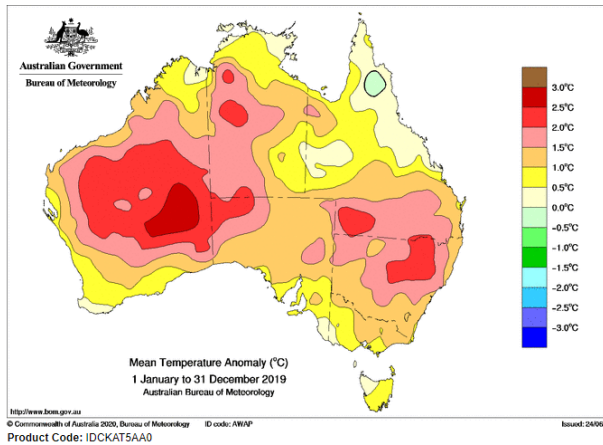
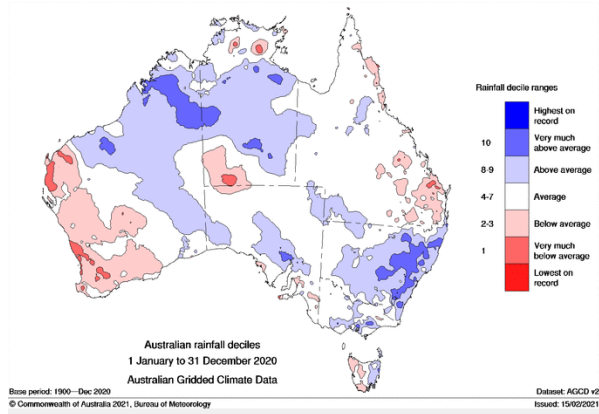
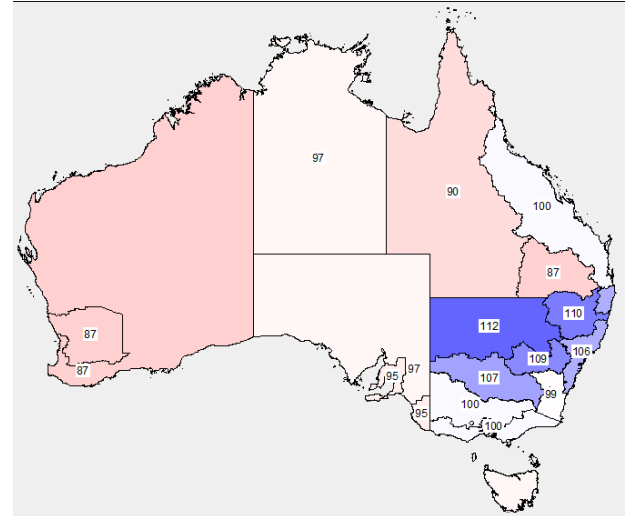


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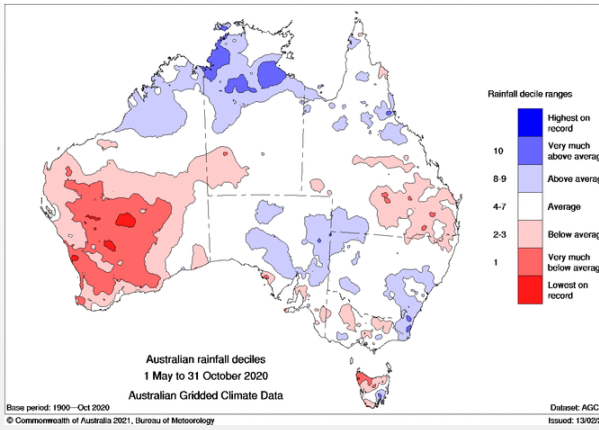
Year 5 (2020)



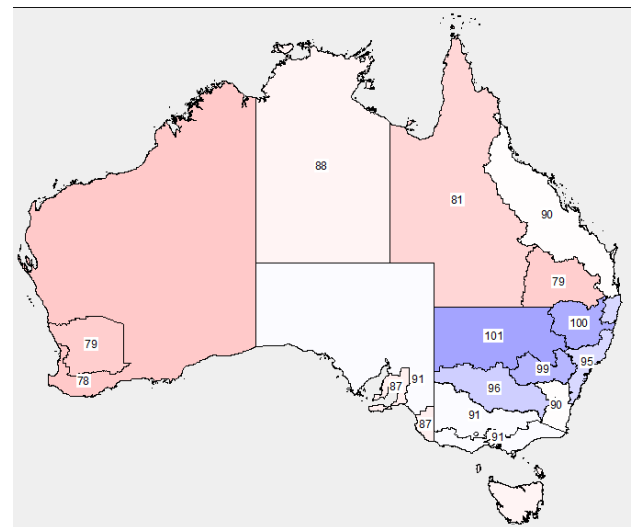
Seasonal index year 5 "2020" = 2020-21



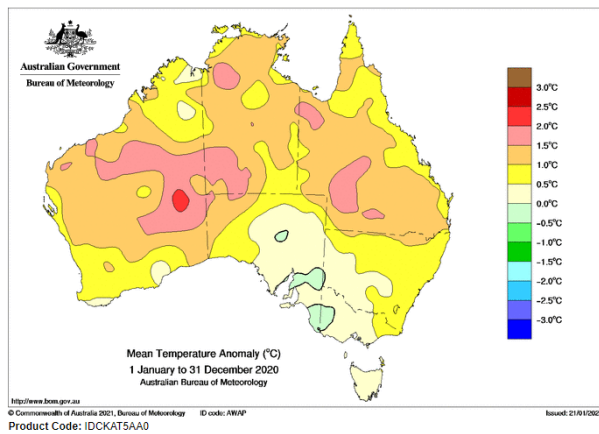
Winter rain year 5:



"2030" yr 5



Mean temperature anomaly year 5:



"2050" yr 5

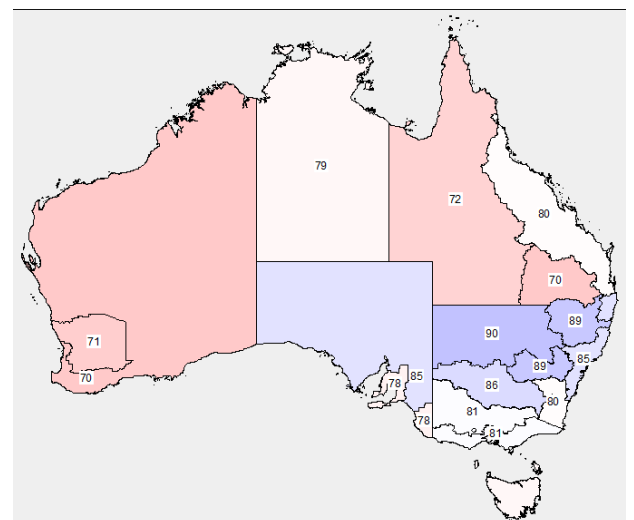
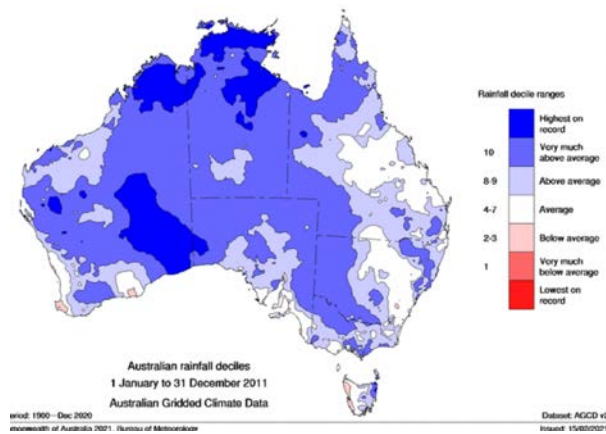
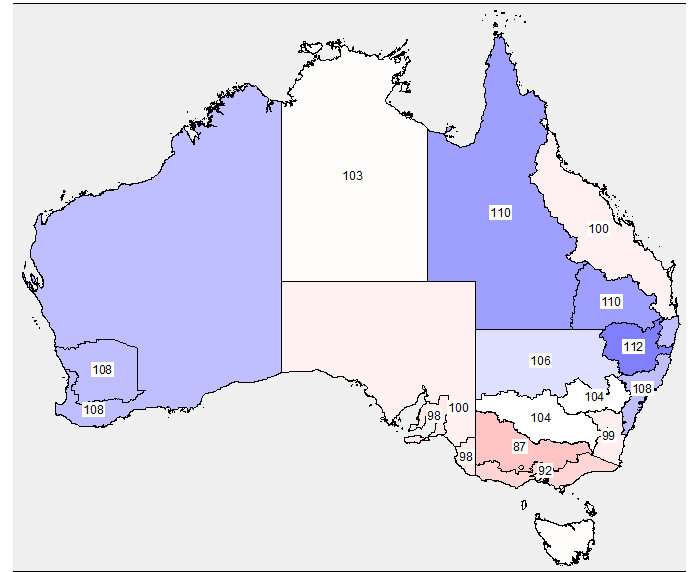


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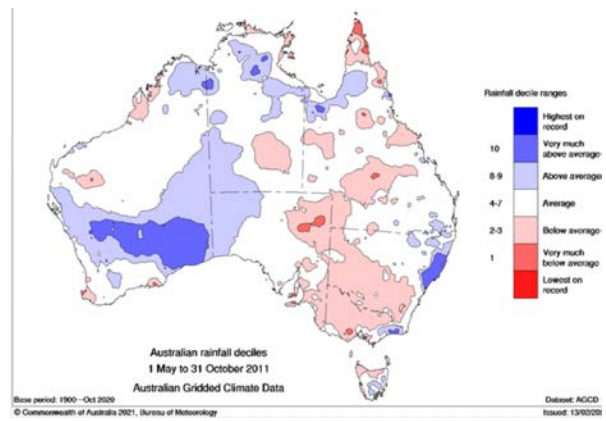
Year 6 based on 2011



Seasonal index year 6 all runs



Winter rain year 6:



Mean temperature anomaly year 6:

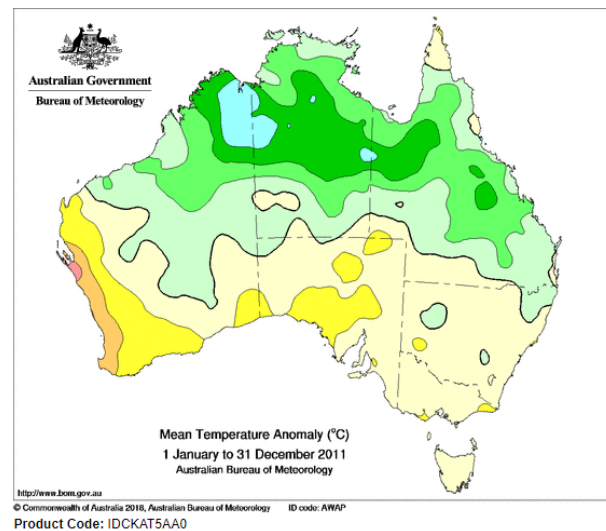
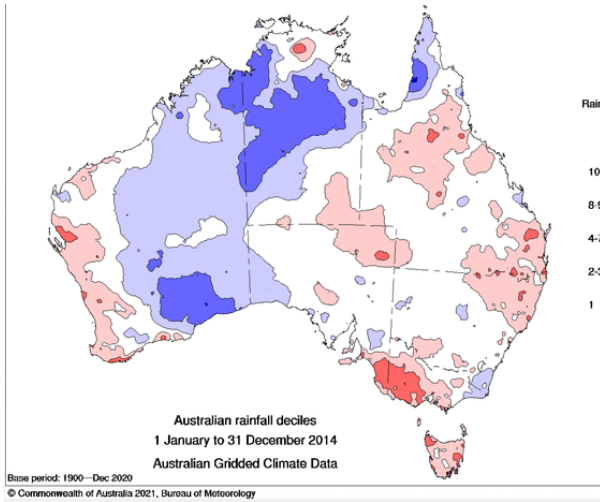
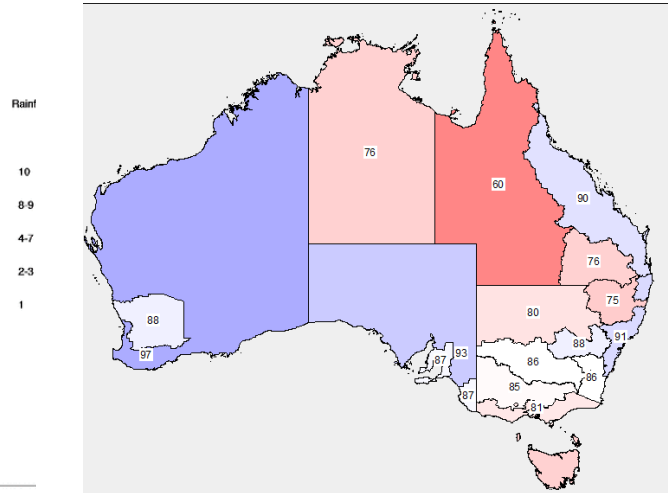


Figure A3 (cont.):

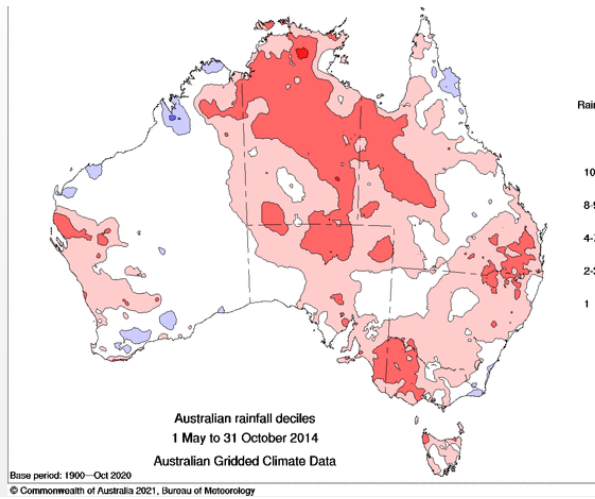
Year 9 based on 2014



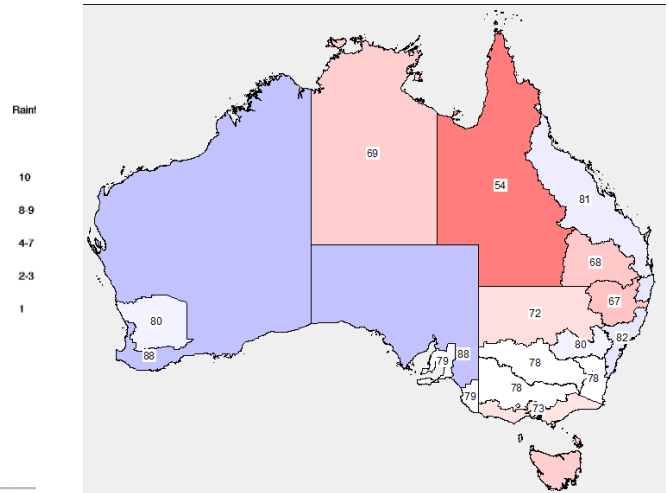
Seasonal index year 9 “2020”



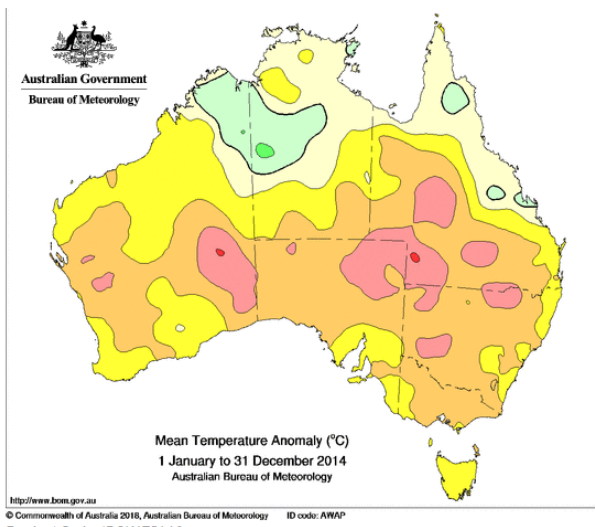
Winter rain year 9:



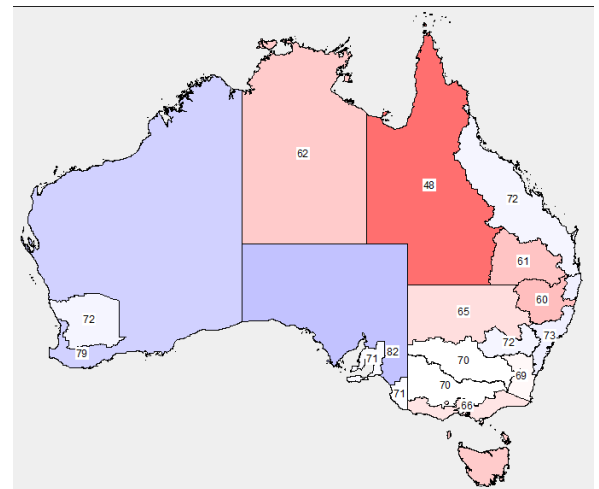
“2030” yr 9



Mean temperature anomaly year 9:



“2050” yr 9



Appendix B: General information on VU-TERM

What is a computable general equilibrium (CGE) model?

A CGE model can be an economy-wide model. In the context of VU-TERM, it is an economy-wide model that also includes small-region representation. Unlike an input-output model which solves either for quantities or for prices, but not both at once, a CGE model solves for both prices and quantities together.

CGE models can be either comparative static or dynamic. Comparative static models are easier to run than dynamic models. However, comparative static results are in some respects harder to explain. Results are reported as changes from a base case – at some point in the future. The only base case defined in a comparative static model is the initial database.

In dynamic models, we prepare a forecast baseline. This may include forecast increases in macroeconomic variables, technological change and taste changes. For example, agricultural productivity historically has grown by 1 to 2% per annum, so productivity growth of this magnitude is imposed on the forecast baseline.

When we report results in a dynamic model, they are as cumulative deviations from the forecast baseline. That is, the modelled impacts of a farm productivity study will be the marginal contribution of productivity shocks ascribed in addition to those of the forecast baseline.

Dynamic CGE modelling

Dynamic models trace the effects of ascribed direct impacts across time periods. The theoretical basis of dynamics is in linkages between investment and capital across time, and the balance of trade and net foreign liabilities. Investment and balance of trade outcomes are flows that a comparative static model includes. Capital and net foreign liabilities are stocks that require a dynamic model.

Dynamic VU-TERM combines much of the theory of dynamic national models (see Dixon and Rimmer, 2002) with bottom-up, regional representation. That is, each region in VU-TERM has its own production functions, household demands, input-output database and inter-regional trade matrices (Figure A1 is a map of regions for which individual representation is possible). This enables us to model relatively local issues.

Dynamic VU-TERM

TERM was originally developed by Mark Horridge at the Centre of Policy Studies (see <https://www.copsmodels.com/term.htm>). Since then, Glyn Wittwer has developed a dynamic version of the model, an application of which Wittwer *et al.* (2005) is an example.

In dynamic VU-TERM, we use an underlying forecast. This may be based on the macro forecasts of other agencies. The underlying forecast or baseline gives us a year-by-year “business as usual” case.

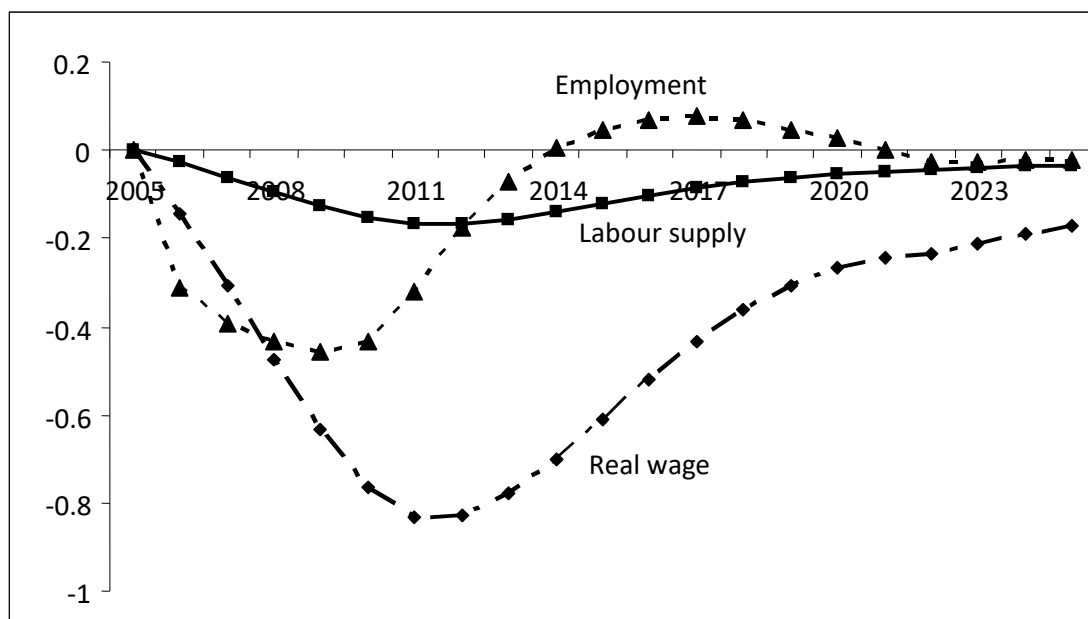
Typical variables to be reported in the policy scenario relative to a baseline forecast are regional real GDP, employment and aggregate consumption. Industry level results are also available.

Labour market – forecast v. policy scenario

In the theory of regional labour market adjustment, if regional labour market conditions improve or deteriorate relative to forecast, adjustment occurs in the short term mainly via changes in employment. Regional wages adjust sluggishly, with gradual adjustment in regional labour market supply (i.e., through migration between regions). Real wages will fall or rise to close the gap between employment and slowly adjusting labour supply. Once the deviation in employment is equal to the deviation in labour supply, real wages reach a turning point (either they bottom out, in the case of a weakening labour market, or peak, in the case of strengthened

labour market conditions). Within this theory, adjustment in the longer term occurs via a combination of altered regional labour supply and real wages that deviate relative to those in other regions. Figure A3 shows an example, in which weakened labour market conditions in a region lead to unemployment in the short run and a lower real wage in the region in the long run.

Figure A1: An example of a weakened regional labour market with eventual recovery (% change from forecast)



Production technologies

VU-TERM contains variables describing: primary-factor and intermediate-input-saving technical change in current production; input-saving technical change in capital creation; and input-saving technical change in the provision of margin services (e.g. transport and retail trade).

VU-TERM's unique treatment of transport to assess the regional benefits of the project

The supply of margins originating in one region can lower the costs of moving goods between regions further afield. Previous multi-regional models assign the margins supply of a sale either to the origin or destination of the sale.

GEMPACK software

Dynamic VU-TERM uses GEMPACK software for implementation (Horridge, *et al.* 2018).

References and examples of published applications

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