The Australian Journal of
Agricultural and Resource Economics

Australian Journal of Agricultural and Resource Economics, 65, pp. 918–936

Estimating the economic impacts of the 2017–2019 drought and 2019–2020 bushfires on regional NSW and the rest of Australia

Glyn Wittwer and Robert Waschik†

Much of New South Wales and southern Queensland suffered from extreme drought from 2017 to 2019. This study models drought and bushfires impacts using VU-TERM, a multi-regional, dynamic CGE model. Prolonged drought pushed national real GDP to 0.7 per cent or more below base in 2018–2019 and 2019–2020. NSW's real GDP fell relative to forecast by 1.1 per cent or $6.9 billion in 2018–2019 and 1.6 per cent or $10.2 billion in 2019–2020. These impacts reflect a severe diminution of farm output, given that agriculture accounts for around 1.6 per cent of NSW's income. Bushfires exacerbated 2019–2020 losses. We assume that there is a full recovery in seasonal conditions in 2020. However, prolonged drought and bushfire destruction deplete farm capital through depressed investment and diminished herd numbers. Consequently, the income earning capacity of farms in recovery remains below that of a no drought base. The net present value of the national welfare loss is $63 billion, split between $53 billion in losses from drought and $10 billion from bushfires. The latter excludes any valuation of human lives lost, flora, fauna or forestry destruction. In the longer term, adaptation and policy responses will need to reflect the expectation of increased frequency of adverse climatic events.

Key words: regional drought impacts, seasonal recovery, welfare.

JEL classifications: Q11, Q15, C68

1. Introduction

Drought is a natural part of Australia's seasonal cycles. There is some evidence that the frequency and severity of drought are worsening with climate change (Cai et al., 2014). A drought started in northern New South Wales (NSW) and southern Queensland in 2017. A cursory glance at annual rainfall deficits in the northern half of NSW shows no worse than decile 2 or 3 rainfall in 2017. However, maximum temperatures in key farming areas of NSW were more than 2 degrees C above average in 2017 (see Appendix Figures S2 and S3). High temperatures combined with far below-average winter rainfall in 2017 worsened the severity of the drought. Rainfall deficits worsened in 2018, while average temperature maxima remained far above average over much of the state. The Bureau of Meteorology described 2019 as

† Glyn Wittwer (e-mail: glyn.wittwer@vu.edu.au) is a Professorial Fellow at the Centre of Policy Studies, Victoria University, Level 14/300 Flinders Street, Melbourne, Victoria 3000, Australia. Robert Waschik is a Associate Professor at the Centre of Policy Studies, Victoria University, Level 14/300 Flinders Street, Melbourne, Victoria 3000, Australia.

doi: 10.1111/1467-8489.12441

the warmest and driest year in Australia on record.[1] Abnormally high temperatures and a decline in winter rains in these 3 years resulted in effective rainfall deficits that were even more severe than recorded rainfall deficits.

The number of economic studies on drought in Australia reflects the frequency of such events. Duloy and Woodland (1967) attempted to link drought impacts to macroeconomic impacts. More recent studies have reflected the policy importance of the Murray–Darling Basin. A number of studies have analysed the impacts of drought on irrigation allocations (Adamson, et al., 2009; Qureshi et al., 2014; Qureshi et al., 2015). However, while the basin accounts for 40 per cent of national farm output, irrigated production accounts only 35 per cent of basin farm output or 14 per cent of national farm output (ABS, 2019). Clearly, drought impacts extend far beyond the Murray–Darling Basin.

The 2002 drought was, at the time, the worst recorded in a century. Horridge et al., (2005) analysed the regional economic impacts in the first application of TERM (The Enormous Regional Model). They estimated economic losses approximately double those estimated by the Reserve Bank of Australia (2002) and subsequently verified the magnitude of drought-induced state-level losses.[2] The objective of this study is to model the extreme drought that impacted much of New South Wales and southern Queensland from 2017 to 2019, as well as the subsequent bushfires that caused considerable losses over 2019–2020. As such, this study considers the impacts of both drought and bushfires with a regional focus that extends well beyond the Murray–Darling Basin.

2. Economy-wide modelling of drought and bushfires

This study uses the Dynamic VU-TERM (The Enormous Regional Model) computable general equilibrium (CGE) model to estimate the economic impacts of the 2017–2019 drought and 2019–2020 bushfires on the regions of NSW and a composite rest of Australia region (Horridge et al., 2005).[3] Dynamic VU-TERM combines much of the theory of dynamic national models (see Dixon & Rimmer, 2002) with bottom-up, regional representation. That is, each region in dynamic VU-TERM has its own production functions, household demands, input–output database and inter-regional trade matrices. Regions are linked by inter-regional trade matrices and labour mobility. The model enables us to model relatively local issues. By basing modelling on a comprehensive multi-regional database, we are able to estimate the marginal impacts of drought and bushfires on regional economies. The

[1] See http://media.bom.gov.au/releases/739/annual-climate-statement-2019-periods-of-extreme-heat-in-2019-bookend-australias-warmest-and-driest-year-on-record/

[2] Based on https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5220.02003-04 and earlier releases

[3] Interstate regions severely impacted by drought and bushfires over this period include southern Queensland, north-east Victoria and East Gippsland in Victoria, and Kangaroo Island and the Adelaide Hills in South Australia.

approach enables us to depict both regional economic losses, which may be severe, and national losses including welfare impacts. The model could be applied also to a broader array of climate-related economic disruptions using hypothetical rather than actual scenarios.

Wittwer and Griffith (2011) modelled the impacts of the 2006–2009 drought on the southern Murray–Darling Basin. Since headwater flows fell far below those of typical years in the southern basin, water allocations to irrigators fell sharply for 2 years, threatening supplies to perennial plantings. Irrigation water shortfalls and drought-affected dryland productivity each contributed to economic losses. Water trading was a key part of the response to the 2006–2009 drought. The 2017–2019 drought affected mainly southern Queensland, virtually all of the farming regions of NSW and for 1 year, at least, farms in northern Victoria. The drought impacted on irrigated activities in the northern basin, where inter-regional water trading is not possible, and less so on the southern basin. In the latter, the main impacts were on dryland agriculture. The present study differs from the approach of Wittwer and Griffith (2011), which used TERM-H2O, in that dynamic drought modelling extends beyond the Murray–Darling Basin.

We report model results as deviations due to drought and bushfires from a business-as-usual baseline. The model includes 30 sectors, 10 of which cover different cropping and livestock activities (see the Appendix for more detail on the sectoral aggregation). In the regional dimension, the model depicts 11 regions within NSW, including, under the ABS classification, SA4 regions inland plus composite coastal regions covering Sydney, Newcastle and Illawarra (see the Appendix Figure S1 for more detail on the regional aggregation). Dynamic VU-TERM uses GEMPACK software for implementation (Horridge et al., 2018).

3. Preparing inputs to VU-TERM

3.1 Drought impacts

Previous drought studies based on TERM models include Horridge et al., (2005), which used a comparative static version to depict the 2002–2003 drought. Wittwer and Griffith (2011) used a dynamic version to depict the impact of the 2006–2009 drought on the Murray–Darling Basin. Since VU-TERM does not include water accounts, the impacts of drought-induced water availability on the irrigated annuals, rice and cotton, require a reduction in factors other than water. Land and capital available to this sector were shocked to reflect the lack of water.

The simulation starts at 2015–2016 (i.e. year ending 30 June 2016). The following year 2016–2017 is depicted as a better than average year for agriculture due to above-average rainfall across most of inland NSW. 2017–2018 is depicted as a moderate drought in northern NSW, with crop data indicating a below-average season elsewhere. In 2018–2019 and 2019–2020, modelling depicts a worsening drought that spread state-wide (see Appendix Figures S2 and S3). Direct losses for the 3-year period are based in part on ABARES crop reports and partly on the authors' estimates derived in collaboration with the NSW Department of Premier and Cabinet.[4] As an example, calculations based on ABARES data indicate that 2019–2020 wheat output in NSW was 33 per cent of the 10-year average. Section 2.7 outlines links between direct shocks and modelled outcomes.

3.2 Estimating direct bushfire losses across eastern Australia for 2019–2020

Fires started in southern Queensland and northern New South Wales in early September 2019 and in more southerly regions over the following weeks and months. Lightning ignited the Gospers Hill (north west of Sydney) fire on 26 October 2019. It was eventually contained in mid-January after burning through 512,000 hectares. Fires burnt through thousands of hectares of forestry and conservation land in NSW and north-eastern and eastern Victoria. Eventual national destruction included over 3 million hectares of conservation land, more than 1.5 million hectares of forests and plantations and over 820,000 hectares of agricultural land in south-eastern Australia. NSW losses included more than 2.5 million hectares of conservation land, 750,000 hectares of forests and plantations and 559,000 hectares of farmland. More than 2400 houses were destroyed in New South Wales out of more than 3000 nationally. In New South Wales, around 10,500 sheep and 3440 cattle were lost in fires. National losses were more than 63,000 sheep and 8400 cattle.

Due to national farmland destruction of over 820,000 hectares, an estimated 67,000 kilometres of fencing were destroyed, with a replacement cost of $600 million, based on $7500 per kilometre for fence replacement plus $1500 per kilometre for clean-up costs. Other capital replacement costs include around 3000 homes at $1.2 billion, 5800 other buildings at $870 million, 14,000 cars at $210 million and 3000 items of farm machinery at a replacement cost of $180 million.[5]

[4] https://www.agriculture.gov.au/abares/research-topics/agricultural-outlook/australian-crop-report/new-south-wales

[5] The Adelaide Hills fire that destroyed around one tenth of the region's vineyards and over 80 houses started on December 20. Fires wrought destruction on the western third of Kangaroo Island, South Australia, in January, destroying more livestock (mainly sheep) than any fire event over the summer. These losses are ascribed to the rest of Australia region. Agriculture Victoria estimated destruction of around 22,000 tonnes of hay and silage (http://agriculture.vic.gov.au/agriculture/emergencies/recovery/current-incidents/agricultural-impact-assessment-data). Online sources used to compile these estimates include: https://www.agriinvestor.com/agricultural-land-comprises-14-of-total-area-burned-by-australian-bushfires/ https://www.abc.net.au/news/2020-01-05/fire-bushfire-dead-livestock-farmers-agforce-animal-carcasses/11841868 https://www.begadistrictnews.com.au/story/6580090/telstra-faces-biggest-disaster/?cs=509 https://www.beefcentral.com/news/bushfire-livestock-loss-estimates-downgraded/ https://www.macleayargus.com.au/story/6504487/the-devastating-toll-of-the-carrai-east-fire-becomes-clear-more-than-50-homes-destroyed/

Based on limited information, damage to telecommunication towers amounted to $33 million with damage of $110 million to electricity infrastructure. Smoke damage to a large proportion of the grapes in the Lower Hunter and Yass-Young regions made them unsuitable for wine production.We based the regional distribution of bushfire losses on information from news reports and various websites (see footnote 4).

3.3 Costs arising from health, injury and trauma

The capital losses from fires over 2019–2020 may amount to around $3 billion, leaving aside native flora and fauna losses. But the costs of bushfires extend far beyond capital losses. In the absence of data on the number of firefighting injuries, we assume that there were 1800 injuries, each with associated medical costs of $5000 and labour productivity losses of $5000. These costs total $18 million.

Firefighters suffer a high rate of post-traumatic stress disorder.[6] There are approximately 20,000 professionals and over 150,000 volunteer firefighters in Australia. Let us assume that the trauma of firefighting efforts results in PTSD in one quarter of professional firefighters and one fifth of volunteers, and that it impacts adversely on their well-being for 3 months. A disruption equivalent to 40 per cent of wages for 3 months, based on earning capacity of $80000 per annum, would be $280 million. Additional counselling costs for PTSD sufferers, at $1000 per person, amount to $35 million.

Health costs due to smoke pollution are high. For months, large populations around Sydney, Newcastle, Wollongong and Canberra suffered from air quality reported at hazardous levels by the New South Wales Department of Planning, Industry and Environment.[7] Up to 60 days of hazardous levels were recorded after the fires started. The calculations used in this study were based on one tenth of the population suffering from asthma and losing half of their labour productivity on hazardous days. This calculation amounts to labour productivity losses of $1.6 billion, though it may understate the number of days that adversely affected health.

Arriagada et al., (2020) estimated that bushfires impacts included 417 additional deaths, 1124 additional hospital admission for cardiovascular cases, 2027 additional hospital admission for respiratory cases and 130 emergency department attendances for asthma. These median estimates may result in additional medical costs of over $30 million (based on $10,000 per admission). Value of human life calculations, not used in VU-TERM modelling, could be deducted directly from the modelled welfare calculation. The estimate of smoke-related deaths provided by Arriagada *et al.* far exceeds the number of direct deaths (34) in the fires. Each of the above impacts is

[6] https://www.verywellmind.com/rates-of-ptsd-in-firefighters-2797428
[7] https://www.dpie.nsw.gov.au/air-quality/current-air-quality

ascribed to dynamic VU-TERM as a temporary deterioration in labour productivity in fire-affected regions.

3.4 Idle capital v. capital destruction

The dynamic theory of capital accumulation in VU-TERM follows Dixon and Rimmer (2002). Industry level investment in most industries in normal years is a function of the rate of return on capital. Capital stocks in year t (K_t), omitting industry and region subscripts, are as follows:

$$K_t = (1 - \partial)K_{t-1} + I_{t-1} + sK_t \tag{1}$$

The rate of depreciation is ∂ and I_{t-1} is investment in the previous year. The shifter sK_t in equation (1) is used in two different ways in modelling drought and bushfires. First, some farm capital and downstream processing capital may be underutilised in response to drought. For example, rice mills in Riverina may be mothballed for several years during prolonged drought. When rains return, idle capital is put back into use. The earlier drought study using a dynamic TERM model (Wittwer & Griffith, 2011) used a theory of excess capacity to put a floor on how much rates of return fall during a drought-induced downturn, based on Dixon and Rimmer (2010). This theory made sK_t endogenous. In the present study, this shifter is kept exogenous and shocked, being brought back to base in 2019–2020, after which $s = 0$.

Second, capital is destroyed due to drought and bushfires. Sales of livestock for slaughter may accelerate as drought worsens. Livestock may be culled when the costs of purchasing feed become prohibitive. In addition, livestock is among the various forms of capital lost to bushfires. The commodity composition of investment differs for each industry in the model. For example, livestock sectors include own inputs as part of herd dynamics. Recovery of capital stocks after destruction is only possible through additional investment in succeeding years. That is, the shifter sK_t does not return to base in the case of capital destruction.

3.5 The treatment of insurance

The role of insurance is to spread losses among many who are at risk and to spread losses over time. In this study, insurance payments made in 2020–2021 are $1.5 billion, reflecting partial coverage of capital losses. Within dynamic VU-TERM, insurance payouts are ascribed in the year of payout as a shock to the balance of trade. That is, insured losses are shared with the rest of the world. A payout is equivalent to a one-off reduction in net foreign liabilities, the level of which otherwise depends on the previous period's liability stock, the balance of trade flow and interest payments on the stock. Insurance premiums are treated within the model as an annual cost for all relevant users. Restorative investment in succeeding years is funded in part by foreign borrowing, the usual mechanism, and in part by insurance payouts.

After the year of insurance payouts, insurance premiums in industries and households in regions suffering capital losses are doubled. These premiums rise by $300 million nationally but are limited to directly affected regions.

3.6 Modified theory

Livestock output within the model is depicted via land productivity shocks. The reason for choosing land productivity instead of total factor productivity is that within the modified theory of VU-TERM prepared for this study, land is substitutable with hay & fodder within the production function of the livestock sectors. Within this theory, once pastures fail due to drought, farmers turn to purchases or on-farm stores of hay and fodder to feed their livestock.

3.7 Modelled outcomes

We start by examining the state-wide macro results for NSW, which reflect the shocks to the model. We explain GDP as a function of primary factors (FAC_j, including capital, land and labour) and underlying technology ($1/A$):

$$GDP = f\left(FACj, \frac{1}{A}\right) \tag{2}$$

Table 1 shows the contributions of farm sectors to regional GDP losses in 2019–2020. Row 1 shows the share of farm output in regional GDP in the base year. The farm shares of GDP for Far West –Orana (15 per cent) and New England – North West (18.6 per cent) are the largest among the regions shown. Also, these two northern NSW regions suffered the most severe drought. Therefore, row 12 shows that these two regions have the largest contributions from farm outputs to regional real GDP losses. Depressed farm incomes result in a decline in household spending, which in turn reduces demand for goods and services. Consequently, in Far West – Orana and New England – North West, output declines in services, making a negative contribution to total real GDP (row 13).

In other regions, much of the gap between the farm contribution to real GDP losses (row 12) and total GDP losses in 2019–2020 (row 13) reflects the impact of bushfires. The largest modelled losses within NSW due to bushfires are in the Capital Region, Coast NSW, Coffs Harbour-Grafton and Southern Highlands – Shoalhaven.

The contribution of each sector i in a given region to deviations in real regional GDP, in Table 1, is computed using.

Table 1 NSW farm sector contributions to deviations in regional GDP (% of GDP), 2019–2020

		CapitalReg	CoastNSW	CentralWest	CoffsGraft	FarWestOrana	HunterExnWC	Murray	NewEngNthWst	RichTweed	Riverina	SthHiShoal
Farm % of GDP	(1)	2.5	0.2	7.1	2.4	15.0	0.9	14.0	18.6	1.8	14.0	0.6
Sheep	(2)	−0.13	0	−0.17	0	−0.44	0	−0.16	−0.12	0	−0.09	0
BeefCattle (3)	(3)	−0.14	0	−0.19	−0.04	−0.60	−0.07	−0.18	−0.74	−0.01	−0.14	−0.03
DairyCattle	(4)	−0.03	0	−0.02	−0.01	−0.01	−0.01	−0.06	−0.01	0	−0.01	−0.04
OthLivstock	(5)	−0.02	0	−0.03	0	0	−0.03	−0.06	−0.01	0	−0.05	0
Wheat	(6)	−0.11	0	−1.04	0	−1.68	0	−1.09	−1.28	0	−1.13	0
OthBrdAcrCrp	(7)	−0.14	0	−0.97	0.03	−1.22	−0.02	−1.08	−2.39	0	−1.01	−0.08
Horticulture	(8)	−0.01	0	0	−0.12	−0.01	0	−0.30	0.00	0	−0.34	0
Rice	(9)	0	0	0	0	0.00	0	−0.87	0.00	0	−1.21	0
Cotton	(10)	0	0	−0.06	0	−2.61	0	−0.25	−3.60	0	−0.88	0
HayCerealFod	(11)	−0.08	0	−0.33	0	−0.31	−0.05	−0.37	−0.20	0	−0.18	−0.02
All farm	(12)	−0.66	0.00	−2.81	−0.14	−6.87	−0.18	−4.42	−8.37	−0.01	−5.04	−0.17
Total GDP deviation	(13)	−2.83	−0.74	−3.75	−1.54	−8.72	−0.83	−6.15	−11.07	−0.77	−6.78	−2.57

$$contIND(i) = \frac{RatioGDP}{GDPFAC} * \sum_f FAC(i,j) * [xfac(i,j) - afac(i,j)] \qquad (3)$$

FAC(i,j) refers to primary factor *j* (i.e. land, labour and capital) in industry *i*, and *xfac(i,j)* and *afac(i,j)* the percentage changes in factor demands and factor input requirements per unit of output (i.e. technological change). The values *RatioGDP* (initial = 1.0), *FAC* and *GDPFAC* (=$\Sigma_i \Sigma_j$ *FAC(i,j)*) change over time and between the underlying year-on-year forecast and the scenario deviation. For decomposition, *RatioGDP* is updated using the percentage change in regional real GDP (a quantity change), whereas *GDPFAC* and *FAC* are updated using both price and quantity changes.

Some factor losses (*xfac*) require further explanation. During drought, we observe that on-farm and contractor machinery may be idle due to reduced plantings. Most of this effect is captured by exogenously assuming a reduction in utilised capital (via sK_t in equation (1)). With a return to normal seasons in 2020–2021, capital returns to full utilisation. However, capital remains below base in recovery years due to a drought-induced decline in investment, livestock losses and destruction by bushfires (Figures 1 and 3).

Drought reduces the output that farms can produce from given inputs, implying technological deterioration (i.e. *afac* impacts). This is evident in Figure 1. Real GDP is a macro measure of output, and from 2017-18 to 2019–2020, the percentage fall in real GDP is larger than the percentage fall in labour or utilised capital (i.e. *xfac* variables), with technological deterioration explaining the gap between the percentage deviation in factor inputs and real GDP. Real GDP falls further below base in the three drought years, by 0.4 per cent or \$2.6 billion in 2017–2018, around 1.1 per cent or \$6.9 billion in 2018–2019 and 1.6 per cent or \$10.2 billion in 2019–2020.

Drought weakens the labour market in NSW, with both employment and real wages falling below forecast. Employment falls more than 0.25 per cent

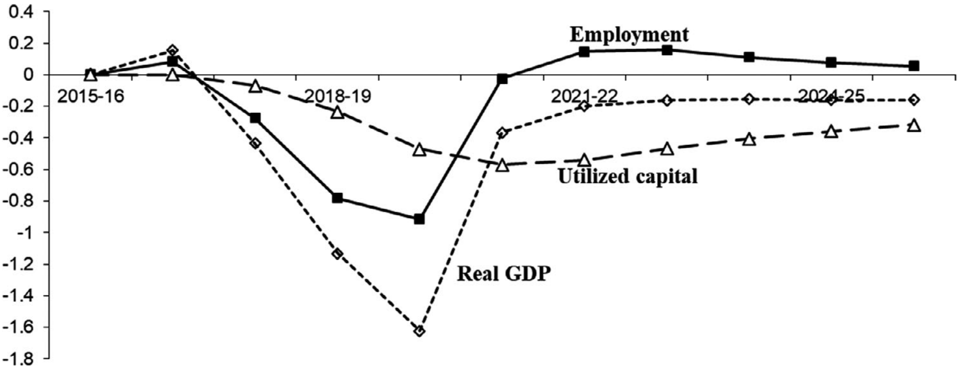

Figure 1 NSW GDP, income side (per cent deviations from base).

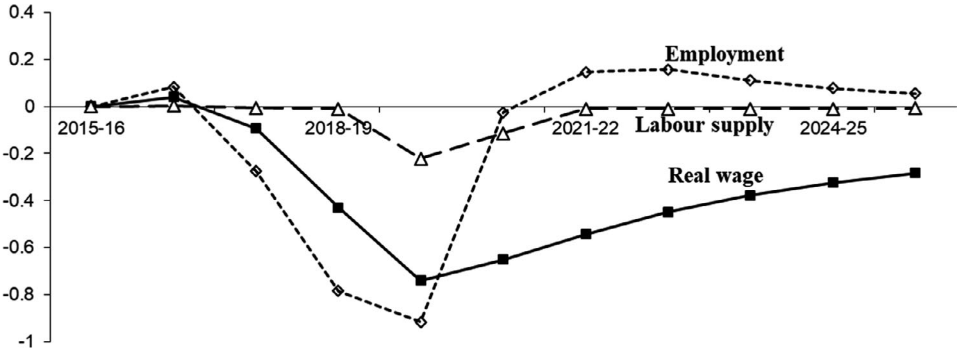

Figure 2 NSW labour market (per cent deviations from base).

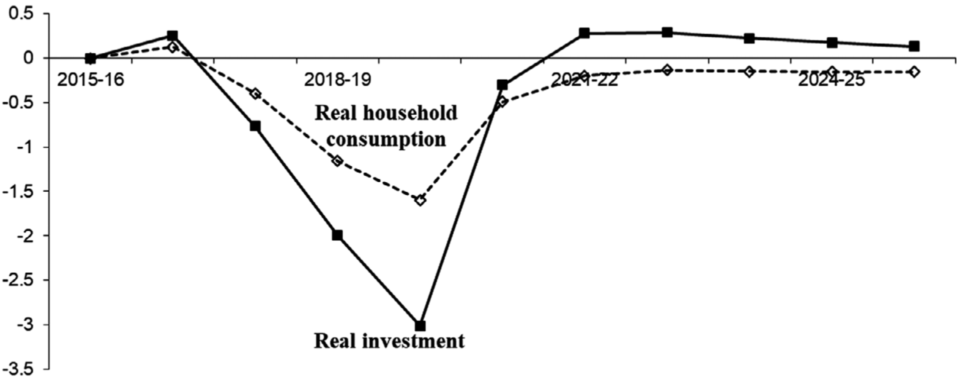

Figure 3 NSW expenditure side (per cent deviations from base).

or 8700 FTE jobs below forecast in 2017–2018, 0.78 per cent or 25,000 FTE jobs below base in 2018–2019 and 0.92 per cent or 29,600 FTE jobs in 2019–2020 (Figure 2 and Table 2). By assumption, real wages adjust sluggishly at the regional level.

In the recovery year (2020–2021), employment moves back to base, and then in the following year (2021–2022), employment rises to 0.15 per cent or around 4800 jobs above forecast in NSW. With a strengthening of the labour market due to a return to normal seasonal conditions, real wages persist below forecast due to sluggish adjustment and diminished capital. As long as labour demand exceeds labour supply, there is upward pressure on wages, causing the negative deviation in the real wage to shrink. By 2025–2026, labour supply and employment have moved towards base. That real wages appear to be stuck below base in 2025–2026 reflects diminished capital relative to base (Figure 1) and hence a diminished marginal product of labour.

Aggregate expenditure and investment at the state level fall below base during the drought years (Figure 3). In the second recovery year, 2021–2022,

Table 2 NSW macro outcomes ($m real or jobs FTE relative to base)

	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021	2021–2022	2022–2023	2023–2024	2024–2025	2025–2026
Real GDP ($m)	903	−2596	−6925	−10198	−2353	−1316	−1101	−1073	−1128	−1167
Household consumption ($m)	448	−1436	−4329	−6112	−1940	−804	−569	−638	−674	−689
Real investment ($m)	342	−1054	−2786	−4274	−435	406	431	339	266	206
Employment (FTE)	2603	−8751	−25143	−29611	−797	4782	5186	3668	2603	1843

investment rises above base. Insurance payouts from bushfires contribute to investment funding in recovery.

At the industry level, Table 3 shows the direct output losses in farm sectors plus the induced losses in services sectors due to reduced aggregate consumption. Losses are exacerbated by capital destruction: dwellings (*OwnerDwellng*) output falls relative to base in part due to diminished spending, and in part due to houses being destroyed by fire in 2019–2020.

At the national level, real GDP in 2018–2019 fell to 0.7 per cent below base (Figure 4). This was a smaller percentage loss than the 1.1 per cent real GDP loss suffered by NSW. While southern Queensland, East Gippsland in Victoria and small patches of South Australia all experienced record rainfall deficits from 2017 to 2019, it did not have the same marginal impact at the state level as in NSW.

Losses in selected SA4 regions of NSW are proportionally far worse than at the state level, reflecting both the relative importance of agriculture in inland regions and the severity of drought in these regions. In the New England – North West SA4 region, real GDP fell to 6 per cent below base in 2017-18 and then more than 10 per cent below base in 2018–2019 and 2019–2020 (Figure 5). Both utilised capital and labour fell to around 2 per cent below base in 2017-18 and around 5 per cent below base in 2018–2019 and 2019–2020. That capital moves only partly back towards base with seasonal recovery reflects the magnitude of the investment downturn between 2017–2018 and 2019–2020 (Figure 6).

The default theory of dynamic VU-TERM includes a theory of sticky wage adjustment, so that as the labour market weakens (strengthens), employment initially falls (rises) with limited movement in real wages (see Wittwer et al., 2005). In succeeding years, real wages fall (rise), thereby lessening the impact on employment. In most drought-impacted regions, we override this assumption by imposing a temporary local downward labour supply shift in 2019–2020 (Figure 7). Without this, we would model an unrealistic partial recovery in employment in drought-affected regions induced by falling regional real wages, even as drought continues.

Table 3 NSW industry outputs ($m change in value-added relative to base, 2020 dollars)

	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021	2021–2022	2022–2023	2023–2024	2024–2025	2025–2026
Sheep	1	−67	−148	−154	−75	−13	−9	−3	3	8
BeefCattle	0	−7	−14	−15	−5	1	2	3	4	5
DairyCattle	−2	−3	−30	−28	−23	−22	−22	−21	−20	−19
OthLivstock	383	−388	−621	−636	−57	−22	−22	−19	−17	−15
Wheat	203	−468	−658	−675	−50	−26	−26	−24	−23	−21
OthBrdAcrCrp	−1	0	−3	−91	−3	−4	−6	−6	−7	−7
Horticulture	0	−33	−76	−82	−75	−50	−5	−5	−5	−5
Rice	0	−192	−474	−488	−94	−29	38	41	44	47
Cotton	31	−43	−131	−136	14	10	11	11	12	13
Hay & fodder	0	−1	−5	−4	−3	−4	−5	−5	−5	−5
ForestFish	2	−139	−348	−351	−255	−136	24	21	19	17
GinnedCotton	12	−31	−81	−83	−14	−6	−2	−1	−1	0
AgriSrvces	−13	40	121	164	93	47	39	38	38	38
Mining	−5	−2	−107	−102	−43	−38	−40	−38	−35	−32
MeatProds	0	0	1	−1	1	0	0	0	0	0
Seafood	3	−4	−15	−20	−5	−6	−5	−4	−3	−3
DairyProds	25	−26	−90	−97	21	−16	−18	−14	−11	−8
OtherFood	−1	4	6	11	8	2	1	0	0	−1
TCFs	−25	74	252	368	292	155	125	114	106	100
OthManuf	5	−15	−57	−91	−23	−14	−14	−15	−15	−16
Utilities	42	−130	−427	−728	−121	19	33	27	20	14
Constructn	71	−178	−527	−671	−70	−24	−11	−21	−28	−33
Trade	8	−36	−153	−245	−65	−45	−50	−54	−57	−60
HotelsCafes	30	−50	−129	−137	−21	−19	−17	−18	−18	−19
RoadFreight	8	−33	−133	−176	−49	−51	−60	−66	−71	−75
OthTransport	58	−163	−554	−2292	−438	32	35	17	9	9
OthService	0	6	−13	−135	−194	−204	−198	−189	−181	−173
OwnerDwellng	16	−66	−256	−420	−112	−45	−39	−44	−48	−51
GovAdmDefOrd	−5	12	37	9	207	103	79	63	52	45
EduHealth	1	−67	−148	−154	−75	−13	−9	−3	3	8

Note: The sum of real value-added does not exactly equal real GDP, as GDP includes indirect taxes.

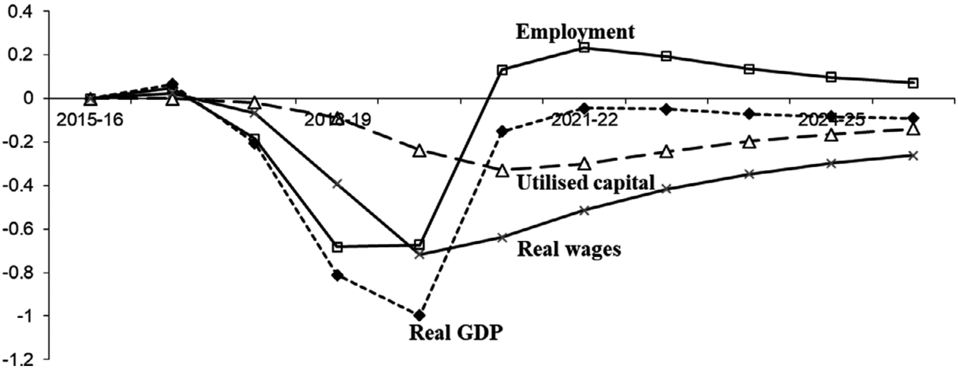

Figure 4 Australia, macro and labour market impacts (per cent deviations from base).

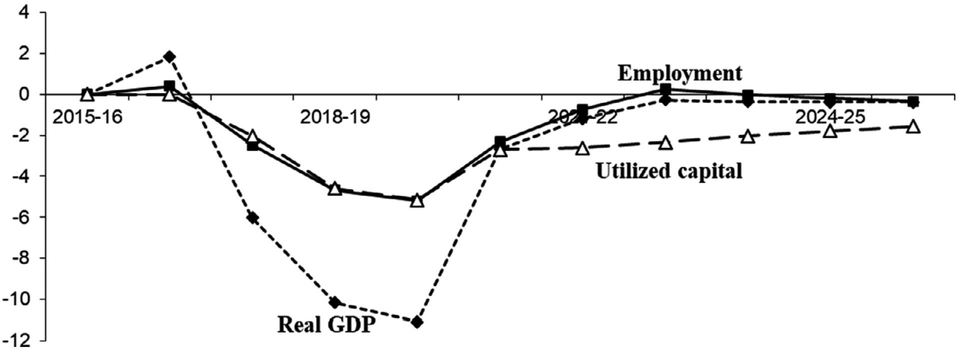

Figure 5 New England – North West SA4, GDP, income side (per cent deviations from base).

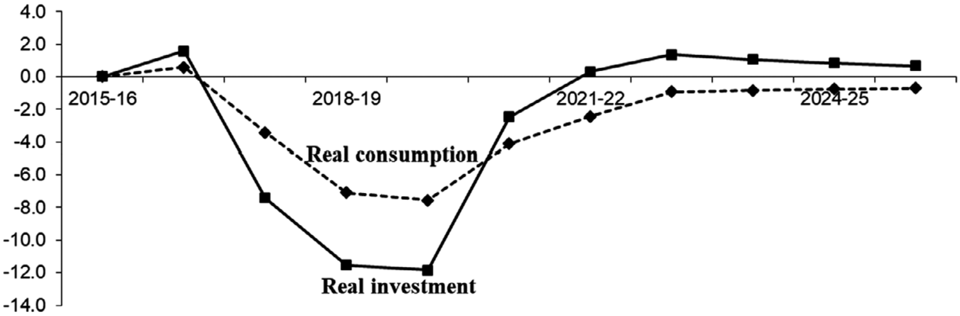

Figure 6 New England – North West SA4, expenditure side (per cent deviations from base).

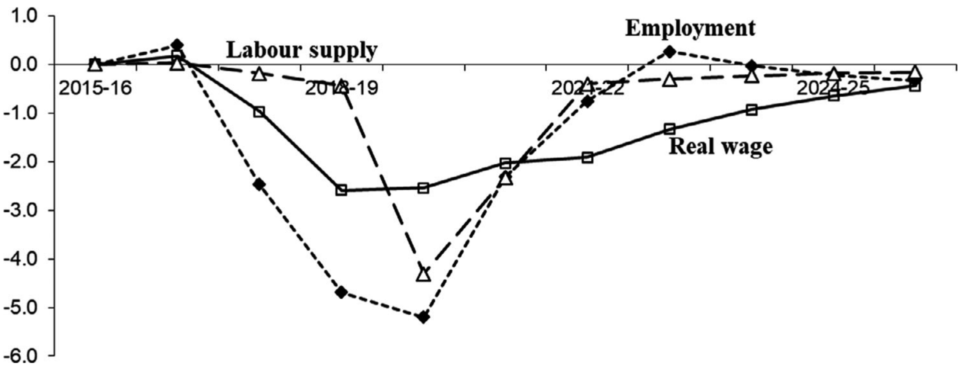

Figure 7 New England – North West SA4, labour market (per cent deviations from base).

Table 4 shows NSW sub-state real GDP and employment deviations from base.[8] While New England-North West experiences the worst losses relative to base, other inland regions, notably Far West – Orana, Murray and

[8] See the map of regions in the Appendix Figure S1.

Table 4 Real GDP and employment by NSW region (% deviations from base)

	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021	2021–2022	2022–2023	2023–2024	2024–2025	2025–2026
Real GDP										
CapitalReg	0.20	−0.40	−1.18	−2.83	−0.80	−0.46	−0.36	0.01	0.00	−0.01
CoastNSW	0.03	−0.09	−0.34	−0.74	−0.02	0.04	0.02	−0.30	−0.23	−0.17
CentralWest	1.19	−1.29	−3.19	−3.75	−0.80	−0.57	−0.40	−0.14	−0.13	−0.12
CoffsGraft	0.06	−0.18	−0.58	−1.54	−0.36	−0.18	−0.14	−0.38	−0.37	−0.34
FarWestOrana	1.82	−5.12	−8.42	−8.72	−1.97	−0.88	−0.39	−0.02	−0.02	−0.01
HunterExNewc	0.04	−0.13	−0.47	−0.83	−0.14	−0.05	−0.03	−0.23	−0.18	−0.14
Murray	1.62	−2.29	−5.43	−6.15	−1.51	−0.82	−0.28	−0.35	−0.38	−0.39
NewEngNthWst	1.82	−6.01	−10.17	−11.07	−2.67	−1.19	−0.28	−0.02	−0.02	−0.02
RichTweed	0.04	−0.15	−0.58	−0.77	−0.18	−0.02	−0.01	−0.17	−0.11	−0.06
Riverina	1.62	−2.63	−5.90	−6.78	−1.79	−0.97	−0.24	−0.50	−0.41	−0.34
SthHiShoal	0.09	−0.23	−0.88	−2.57	−1.05	−0.82	−0.62	0.02	0.00	−0.01
Employment										
CapitalReg	0.11	−0.34	−1.00	−1.62	−0.37	0.00	0.05	0.05	0.05	0.04
CoastNSW	0.05	−0.16	−0.55	−0.61	0.15	0.24	0.19	0.14	0.10	0.07
CentralWest	0.28	−0.57	−1.65	−1.96	−0.69	−0.46	-0.25	−0.14	−0.07	−0.03
CoffsGraft	0.09	−0.31	−0.85	−1.25	−0.13	0.12	0.12	0.09	0.07	0.05
FarWestOrana	0.44	−1.98	−3.46	−3.89	−1.40	−0.49	−0.07	−0.20	−0.30	−0.36
HunterExNewc	0.04	−0.16	−0.55	−0.67	−0.04	0.07	0.08	0.07	0.07	0.06
Murray	0.42	−1.09	−2.85	−3.27	−1.25	−0.55	0.06	0.04	0.03	0.02
NewEngNthWst	0.39	−2.47	−4.69	−5.20	−2.32	−0.75	0.27	−0.02	−0.21	−0.33
RichTweed	0.07	−0.25	−0.85	−1.07	−0.07	0.15	0.14	0.10	0.08	0.06
Riverina	0.36	−0.92	−2.67	−3.17	−1.60	−0.79	−0.04	−0.02	−0.02	−0.02
SthHiShoal	0.11	−0.29	−1.17	−1.91	−0.89	−0.58	−0.33	−0.20	−0.12	−0.07

Riverina, also have marked losses. Coast NSW (Newcastle, Sydney and Illawarra) experiences the smallest proportional decline in real GDP and employment, reflecting a much smaller agricultural share of total income. However, Coast NSW's food processing and transport activities diminish due to drought and, in 2019–2020, bushfires. The region's other services sector which includes domestic and international tourism also has a downturn due to the impact of bushfires on demand.

4. The national welfare impacts of drought and bushfires

We measure welfare at the national level. In addition to the impact on private and public spending over time, we need to account for the scenario's impact on net foreign liabilities and capital stocks with a terminal year calculation. Restoration of capital after a destructive event may appear to be good for an economy, as increased investment relative to base increases employment. However, additional investment requires funding, which in the present study is obtained by a combination of foreign borrowing and insurance payouts. Such funding affects future debt levels and spending power. The deviation in welfare (*dWELF*) at the national level is as follows:

$$dWELF = \sum_d \sum_t \frac{dCON(d,t) + dGOV(d,t)}{(1+r)^t} - \frac{dNFL(z)}{(1+r)^z} + \frac{dKstock(z)}{(1+r)^z} \quad (4)$$

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.

The drought and consequent bushfires diminish national welfare. The net present value of the national welfare loss is \$63 billion, split between \$53 billion in losses from drought and \$10 billion from bushfires. The contribution of capital losses exceeds \$28 billion, reflecting bushfire destruction, drought-induced livestock culling and depressed investment. A potential persistent economic loss in the future may arise from the impact of bushfires on international tourism. The longevity of this impact, based on bushfires tarnishing Australia's tourism image, is debatable. In any case, COVID-19 impacts may diminish the marginal impact of bushfires on international tourism demand. The marginal welfare loss of the ascribed shocks to international tourism (via the aggregated 'other services' sector) is around \$4.7 billion.

The bushfire contribution excludes any valuation of human lives lost, and of flora and fauna destruction. If we value a human life at \$5 million, the 34 lives lost directly plus more than 400 lost due to smoke impacts add more than \$2 billion to welfare losses. Even the most modest valuation of 3 million hectares of conservation land and 1.5 million hectares of forests and plantations burnt out will also add billions to overall welfare losses.

5. Adaptation and policy implications

Ummenhofer et al., (2009) identified the absence of negative Indian Ocean Dipole (IOD) events as the main cause of drought in south-eastern Australia. The authors concluded that since IOD events are predictable out to several months in advance, this should enable improvements in water planning and agricultural management in response to drought. A less optimistic view arises from further work reported by Cai et al., (2014), linking global warming with an increase in the frequency of extreme positive IOD events. Darbyshire et al., (2020) concluded that seasonal forecasts remain of limited value.

Given the probable increased frequency of drought arising from the findings of Cai et al., (2014), farm adaptation measures will be necessary. Either livestock will need to 'follow the rain' if farmers wish to avoid culling, or in higher rainfall districts, farmers will need to adopt some practices used in lower rainfall mixed farming regions, which include having more than a year's supply of on-farm feed storage for when rains fail (Mauldon & Dillon, 1959). Farmers responding to IOD information in the future may adjust annual crop plantings in line with prospective seasonal rain.

What is the role of government? First, public funding of agricultural R&D may assist in developing new crop strains, altered inputs and altered livestock practices that will enhance the response of farmers to climate change. Underinvestment in farm R&D is an ongoing concern of agricultural economists (Mullen, 2007).

Freebairn (1983) advocated a move away from input subsidies in response to drought. Given that many non-farm businesses in rural communities are vulnerable to downturns during drought, transfers to a broad array of households in regional communities will provide a more effective government response. A blip of 1 per cent or so in GDP in national accounts data may mask a deep Keynesian recession at the regional level. Structural change in regional economies implies that the emphasis on farm relief measures during drought may be insufficient and inefficient. In the Murray–Darling Basin, for example, based on ABS 2016 census data, agriculture's share of regional income is now smaller than was the case for all of Australia around 1950 (Butlin, 1985). Communities still suffer severe economic losses from drought, as is shown for the New England-North West SA4 region (Figures 5–7). In drought-induced downturns, local small businesses suffer as spending stops. Drought affects mental and physical health in regional communities: increasing the availability of local counselling services and maintaining regional health services are likely to be more efficient in maintaining regional welfare than temporary farm input subsidies. Since seasonal variation can be dramatic, which in turn causes wide fluctuations in regional incomes, income stabilisation measures should be accessible to all within a region, and not limited to farmers.

Some of the fiscal measures introduced by the Commonwealth and state governments in response to COVID-19 may provide a template for targeted funding in response to severe local drought. In the case of New England-North West, drought-induced losses are comparable in percentage terms to national losses arising from COVID-19 and may be of a longer duration. There has been agreement at both the national and international levels for substantial fiscal responses to the COVID-19 crisis, so as to maintain household incomes and businesses. In the context of the regional impacts of drought, there is also a case for temporary transfers to households. Transfers to households do not translate simply to increased future debt without net benefit. By reducing idle labour and capital at the regional level, such transfers may alleviate drought-induced welfare losses relative to no response, after accounting for the impact on future national debt. Moreover, governments should be conscious of maintaining reasonable public school, hospital, aged care and recreational services in regional communities. Each of these contributes to quality of life and hence regional welfare.

Prolonged drought inevitably raises debate concerning water security. Many inland towns in NSW faced low water availability or ran out of water in 2018 and 2019 (Carbonell et al., 2018). Water infrastructure projects should concentrate on securing supplies for towns and households, and the drinking needs of livestock on farms. If a drought were a rare event, temporary expensive water carting in theory would be cost-effective relative to some water infrastructure projects. In Orange NSW, a local government project enhanced water security by supplementing mains water with stormwater catchment.[9]

Irrigation activities require much greater water volumes per enterprise. Far from drought-proofing regions, new irrigation developments may exacerbate the vulnerability of farms to drought. This is particularly the case if irrigation developments include substantial plantings of perennials. Overall, irrigation works favour fewer businesses and households per unit of expenditure than town-based supplies. In principle, public expenditures on irrigation developments should reflect no more than their potential social value.

In the case of bushfires, accelerated reconstruction in principle enhances welfare relative to slow reconstruction, by restoring business-as-usual activities. The clamour to reduce red tape concerning building regulations needs to be weighed against the advantages of improving the fire resistance of new structures. Unfortunately, COVID-19 restrictions appear to have slowed the reconstruction process. For example, a government-funded clean-up of 736 bushfire ravaged properties in Victoria was only completed in late August 2020, almost 8 months after the fires (Lazzaro, 2020).

The Commonwealth government failed to heed the advice of emergency services experts prior to the 2019–2020 bushfires (Offer, 2019). In contrast, the response of all Australian governments to the COVID-19 pandemic reflected adherence to expert direction. Given the likelihood of an increased frequency of adverse weather events, government policies need to move beyond ad hoc responses. While ongoing provision for temporary transfers to households in drought-affected communities would be a start, governments need to bolster the capacity to deal with disaster. Preparation for responses to weather-related disasters covers a wide span of requirements, such as trained personnel, suitable machinery and equipment, altered building codes, analysis of flood-prone areas and ongoing programmes to retain community awareness of the dangers of extreme events.

A dynamic CGE framework is suitable for analysing an array of adverse events, be they simultaneous or distributed over time. The framework enables the practitioner to ascribe detailed inputs concerning destruction of infrastructure, temporarily idle capital, labour productivity impacts, recovery investment, insurance impacts, industry output effects and transfers to households. The framework provides economy-wide perspectives at both the regional and national level, which may be of use in helping rank policy and adaptation responses.

[9] https://www.orange.nsw.gov.au/water/stormwater/

Data availability statement

The model and data require specialist GEMPACK software to access. The authors will provide data and code in response to any reasonable request.

References

Adamson, D., Mallawaarachchi, T. & Quiggin, J. (2009) Declining inflows and more frequent droughts in the Murray-Darling Basin: climate change, impacts and adaptation. *Australian Journal of Agricultural and Resource Economics*, 53, 354–366.

Arriagada, N., Palmer, A., Bowman, D., Morgan, G., Jalaludin, B. & Johnston, F. (2020). Unprecedented smoke-related health burden associated with the 2019-20 bushfires in eastern Australia. *Medical Journal of Australia*, 213, 282–283. https://doi.org/10.5694/mja2.50545

Australian Bureau of Statistics (ABS) (2019). Gross value of irrigated agricultural production. Available from URL: https://www.abs.gov.au/statistics/industry/agriculture/gross-value-irrigated-agricultural-production/latest-release

Butlin, N. (1985) *Australian National Accounts 1788–1983*. Canberra: Australian National University.

Cai, W., Santoso, A., Wang, G., Weller, E., Wu, L., Ashok, K. et al. (2014) Increased frequency of extreme Indian Ocean Dipole events due to greenhouse warming. *Nature*, 510, 254–258.

Carbonell, R., Notzon, N., Henderson, A. & Ferguson, K. (2018). Drought-hit town of Murrurundi has three months of water left. What happens then? Available from URL: https://www.abc.net.au/news/rural/2018-08-05/the-town-about-to-run-out-of-water/10073762

Darbyshire, R., Crean, J., Cashen, M., Anwar, M.R., Broadfoot, K.M., Simpson, M. et al. (2020) Insights into the value of seasonal climate forecasts to agriculture. *Australian Journal of Agricultural and Resource Economics*, 64, 1,034–1,058. https://doi.org/10.1111/1467-8489.12389

Dixon, P.B. & Rimmer, M.T. (2002) *Dynamic General Equilibrium Modelling for Forecasting and Policy: A Practical Guide and Documentation of MONASH, Contributions to Economic Analysis 256*. Amsterdam: North-Holland.

Dixon, P.B. & Rimmer, M.T. (2010) You can't have a CGE recession without excess capacity. *Economic Modelling*, 28, 602–613.

Duloy, J. & Woodland, A. (1967) Drought and the multiplier. *Australian Journal of Agricultural Economics*, 11, 82–86.

Freebairn, J. (1983) Drought assistance policy. *Australian Journal of Agricultural Economics*, 27, 185–199.

Horridge, J.M., Jerie, M., Mustakinov, D. & Schiffmann, F. (2018) GEMPACK manual, GEMPACK Software, ISBN 978-1-921654-34-3.

Horridge, M., Madden, J. & Wittwer, G. (2005) Using a highly disaggregated multi-regional single-country model to analyse the impacts of the 2002–03 drought on Australia. *Journal of Policy Modelling*, 27, 285–308.

Lazzaro, K. (2020) Taxpayer funded bushfire clean-up in Victoria complete. Available from URL: https://www.abc.net.au/news/2020-08-29/government-funded-bushfire-clean-up-in-victoria-complete/12601938

Mauldon, R. & Dillon, J. (1959) Drought, fodder reserves and stocking rates. *Australian Journal of Agricultural Economics*, 2, 45–57.

Mullen, J. (2007) Productivity growth and the returns from public investment in R&D in Australian broadacre agriculture. *Australian Journal of Agricultural and Resource Economics*, 51, 359–384.

Offer, K. (2019) Ex-emergency chiefs sound climate alarm. Canberra Times, April 10. Available from URL: https://www.canberratimes.com.au/story/6014638/ex-emergency-chiefs-sound-climate-alarm/?cs=14231

Qureshi, M.E., Ahmad, M., Whitten, S. & Kirby, M. (2014) A multi-period positive mathematical programming model for assessing economic impact of drought in the Murray-Darling Basin. *Australia, Economic Modelling*, 39, 293–304.

Qureshi, M.E., Ahmad, M., Whitten, M., Reeson, A. & Kirby, M. (2015) Impact of climate variability including drought on the residual value of irrigation water across the Murray-Darling Basin. *Australia, Water Economics and Policy*, 2, 1550020. https://doi.org/10.1142/S2382624X15500204.

Reserve Bank of Australia (2002). Statement on monetary policy. https://www.rba.gov.au/publications/bulletin/2002/nov/1.html

Ummenhofer, C., England, M.H., McIntosh, P.C., Meyers, G.A., Pook, M.J., Risbey, J.S. et al. (2009) What causes southeast Australia's worst droughts? *Geophysical Research Letters*, 36. https://doi.org/10.1029/2008GL036801.

Wittwer, G. & Griffith, M. (2011) Modelling drought and recovery in the southern Murray-Darling basin. *Australian Journal of Agricultural and Resource Economics*, 55, 342–359.

Wittwer, G., Vere, D., Jones, R. & Griffith, G. (2005) Dynamic general equilibrium analysis of improved weed management in Australia's winter cropping systems. *Australian Journal of Agricultural and Resource Economics*, 49, 363–377.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1 Figure A1: VU-TERM regions in this study. Figure A2: Rainfall deciles, NSW, 2017–2019. Figure A3: Maximum temperature anomalies, NSW, 2017–2019.