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Modelling drought and recovery in the southern Murray-Darling basin*

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The prolonged drought from 2006–07 to 2008–09 in south-eastern Australia presented severe difficulties for dry-land and irrigation farmers in the southern Murray-Darling basin. A dynamic multi-regional computable general equilibrium model (TERM-H2O) is used to estimate the economy-wide small region impacts during and after drought. Drought reduces real GDP in some small regions by up to 20 per cent. Irrigation water trading and farm factor movements alleviate losses. The drought results in an estimated 6000 jobs being lost across the southern basin. Depressed farm investment during drought results in farm capital not returning to baseline levels after drought. Consequently, job numbers in 2017–18 remain 1500 below forecast in the southern basin.

Key words: CGE modelling, drought.

1. Introduction

Australia has one of the most variable rainfall climates in the world. Drought can have devastating impacts on agriculture, including dramatic plunges in crop production, loss of livestock and other farm capital and deterioration in the natural resource base. Australia has traditionally afforded its farmers a great deal of drought support. From the early 1980s, however, this free-flowing support came under attack as unnecessary and distorting (see for example, Freebairn 1983). Drought was removed from the natural disasters list and from 1992 has been covered instead by the National Drought Policy. The National Drought Policy has three aims as follows: to encourage farmers to manage their own risks; to look after the natural resource base; and to encourage a quick recovery (O'Meagher *et al*. 1998).

The aim of this paper is to analyse the regional economic impacts of a prolonged period of recurrent droughts using TERM-H2O, a dynamic computable general equilibrium (CGE) successor to the bottom up, comparative static TERM (The Enormous Regional Model). We concentrate on the regions of the southern Murray-Darling basin (SMDB). One issue concerns

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the dynamics of drought and drought recovery. In particular, we focus on the implications of drought for regional investment and capital. Another issue is the broader regional economic and employment implications of drought. TERM-H2O models the interaction between irrigation and dry-land agriculture in times of drought, allowing re-allocation of resources across these two activities. Finally, modelling of the impacts of drought provides a benchmark for analysing the impacts of the Australian Government's water 'buyback' policy.

Some analysts and lobbyists have asserted that planned reductions in water used by irrigators in the Murray-Darling basin are similar to the effects of drought (Rizza 2010). Regional impacts generated by various models including TERM-H2O (Dixon *et al.* 2010) and an ABARE model (ABARE–BRS 2010) have been dismissed as understating the probable employment impacts of reducing allocations, most notably by Murray-Darling Basin Authority board members (Akerman 2010). It would appear that water buybacks, which started during drought, were blamed for job losses that actually arose from drought. Therefore, there is some value in modelling the impacts of drought and estimated impacts on basin employment.

Drought is hard to model, as it entails substantial inward supply shifts for farm sectors. Large change simulations are a challenge for modellers. Linear programming models are likely to reach unrealistic corner solutions with relatively modest supply shifts. Computable general equilibrium models that include CES functional forms will perform better, but most still struggle in large change cases. Consequently, studies on CGE modelling of drought are rare: the only previous studies of which we are aware are Sherony *et al.* (1991), Horridge *et al.* (2005) using a version of TERM without water accounts and Pauw *et al.* (2010). To depict the impacts of a drought as severe as that in southern Australia from 2006–07 to 2008–09 is an extreme test of a multi-regional CGE model. This paper outlines various theoretical modifications undertaken to improve the modelling of drought in a CGE framework and then applies the model to the period from 2005–06 to 2017–18. In particular, we apply a theory of excess capacity to downstream processing sectors.

Results are explained by starting with naïve calculations and outlining how the theory of the model moves simulated results away from these calculations. In addition, the approach provides some estimate as to the impact of prolonged drought on structural change in predominantly rural regions of south-eastern Australia.

1.1. The prolonged drought of 2006–07 to 2008–09

South-eastern Australia endured recurrent droughts after that of 2002–03. From 2003–04 to 2005–06, there was a partial recovery to near-average rainfall in SMDB. Then, the alpine regions of Victoria and New South Wales, which are the source of the Murray River, suffered record rainfall deficits in the period from 2006–07 to 2008–09.[1] This resulted in recurrent reductions in water allocations throughout the SMDB. The Goulburn–Murray water authority's allocations illustrate the severity of the first decade of the new millennium: it formerly aimed at providing 100 per cent allocations in 97 years of 100 for the Goulburn system (although the authority removed this aim from its website early in 2010), but has failed to do so in five of eight irrigation seasons starting with 2002–03.

The CGE approach enables us to keep in context the contribution of agriculture to ostensibly rural economies. As agriculture's contribution to the national economy has shrunk, so too has its contribution to regional Australia's economies. For example, our estimates of regional GDP shares indicate that the SMDB's contribution from agriculture in 2005–06 was less than 13 per cent (Table 2, row (5)), little more than the national share in 1962–63 when Australia's population was half of its present total (Maddock and McLean 1987). It follows that although drought still depresses regional economies, the potential impacts are not as large as they might have been had the pattern of drought in the first decade of the new millennium occurred several decades ago. That is, rural economies have also diversified over time, with an increasing share of income being accounted for by service sectors.

2. Enhancing the representation of irrigation in TERM

The first application of the original TERM was to the Australian drought of 2002–03 (Horridge *et al.* 2005). The original model underestimated the observed change in the composition of farm output. The model did not include water accounts, did not distinguish between dry-land and irrigation technologies and therefore did not capture factor mobility between dry-land and irrigation activities. Despite its limitations, the model estimated state-wide macro-impacts reasonably well (Horridge *et al.* 2005, Table 4).

Incremental enhancements to TERM started with the inclusion of water accounts (Wittwer 2003). The database of a typical CGE model is based on an input–output structure designated in values. Irrigation water can vary greatly in price between users and years. It is necessary to include volumetric accounts so as to capture differences in water usage per dollar of output between different agricultural outputs. Yet, early applications of this version of TERM did not closely track observed changes in water usage between farm activities in response to changes in water availability. For example, using a version of TERM with water accounts, Young *et al.* (2006) modelled relatively modest declines in rice output in response to worsening water scarcity. This did not tally with available evidence. Water usage in rice production is highly responsive to changes in water scarcity: total water usage in the

[1] A map showing rainfall deciles for the 3 years ending December 2008 is downloadable from http://www.bom.gov.au/jsp/awap/rain/archive.jsp?colour = colour&map = decile&year = 2008&month = 12&period = 36month&area = nat.

Table 1 Water consumption (GL) by crop in the Murray-Darling basin, 2001–02 to 2005–06

	2001–02	2002–03	2003–04	2004–05	2005–06
Livestock pasture	2971	2343	2549	2371	2571
Rice	1978	615	814	619	1252
Cereals (excl. rice)	1015	1230	876	844	782
Cotton	2581	1428	1186	1743	1574
Grapes and fruit	868	916	871	909	928
Vegetables	152	143	194	152	152
Other agriculture	504	475	596	564	460
Total agriculture	10,069	7150	7087	7204	7720

ABS (Australian Bureau of Statistics) (2009a), Table 4.20.

Murray-Darling basin dropped by 29 per cent from 2001–02 to 2002–03; yet, usage for rice production in the region dropped by 70 per cent (Table 1). Following the drought of 2002–03, there has only been one year, 2005–06, in which water usage in rice production has reached half of what it was in the years prior to 2002–03.

Dixon *et al*. (2010) modified TERM on the supply side to reflect the mobility of irrigation water between competing uses. TERM-H2O, the revised model, includes the following:

- a split in most farm sectors between irrigated and dry-land technologies;
- three types of farm land, irrigated land, irrigable land,[2] and dry land;
- owner/operator inputs; and
- specific capital for livestock sectors and for tree and vine crops.

When water availability changes within TERM-H2O, farm factors such as irrigable land, farm capital and owner/operator inputs may move between irrigation and dry-land technologies, or between different irrigation sectors and different dry-land sectors. Specific capital is immobile between sectors, reflecting the relative inflexibility of perennial cropping. The main impacts of these theoretical modifications are to widen differences in the responsiveness of different activities to changes in water availability while increasing farm factor mobility. This was a first step in undertaking large change simulations.

The next step in modelling irrigation sectors and regions in TERM-H2O was to move from a representation at the statistical division level to the statistical sub-division (SSD) level. In the context of irrigation, the finer level of representation aligns more closely with catchment regions. This causes further modelling difficulties. The statistical division level tends to include regions dominated in economic structure by large towns. This

[2] In TERM-H2O, irrigation sectors require a fixed volume of water per hectare. When water scarcity worsens, either irrigable land re-allocates to activities that require less water per hectare or irrigable land switches to dry-land farming. Dry land cannot be used in irrigation activities.

makes these regions more service intensive and less agriculture intensive than is the case for rural regions at the SSD level.[3] In addition, while at the statistical division level, farm output price rises are moderated by the impact on production costs of downstream processing sectors, at the SSD level, not all regions contain substantial downstream processing sectors. Therefore, the higher concentration of farm activity may result in farm output prices making a larger contribution to terms-of-trade impacts in the smaller regions without being offset significantly by increased costs to downstream users in the same region. Consequently, the model without further modifications may predict unrealistically large terms-of-trade gains in rural regions.

The consumption function in TERM links nominal consumption to disposable income. Terms-of-trade gains affect the price of regional exports (interregional plus international), which are included in GDP but not consumption. Regional imports are included in household consumption but not GDP. Therefore, an increase in price of regional exports relative to regional imports (a terms-of-trade gain) raises the ratio of regional real consumption to real GDP. There is a danger that we may model perverse real consumption gains in small regions in times of drought. Rectifying this requires a further theoretical modification.

2.1. Why not make demands for farm products more elastic?

Pen-and-paper models often use the small country assumption in which demands are elastic. This simplifies the impacts of inward supply shifts by guaranteeing that revenues fall as output decreases. But it can also lead to quite unrealistic results. For example, if Australia's farm supply curves move inwards due to drought, and if demands are highly elastic, would not imports substantially or entirely replace domestic supplies? In practice, there is a degree of substitution towards food imports during drought, but for most commodities there is no evidence of a complete switch to imports. Armington (1969, 1970) helped modellers move towards more realistic results (i.e., away from flip-flop solutions) by introducing the assumption of imperfect import substitutability.

More generally, food products follow Engel's law with income elasticities below one. Usual functional forms for household demands in CGE models (Stone-Geary or constant difference of elasticities forms, suitable for broad aggregations of commodities where specific substitutability is not an issue) result in household demand elasticities for food around −0.5 or even smaller. TERM-H2O has export demand elasticities for most commodities other than

[3] Farm income in the Murray statistical division in the 2006 TERM database accounted for around 12 per cent of total regional income. One town, Albury, accounts for 40 per cent of the population of Murray (Australian Bureau of Statistics (ABS) 2009b). Within the Murray statistical division, the farm share of GDP excluding Albury SSD (i.e., the Central Murray and Murray-Darling statistical sub-divisions) exceeds 20 per cent.

wool of −4.[4] The higher the share of domestic consumption of Australia's agricultural production, the more likely are outputs to have relatively low total share-weighted demand elasticities.

A CGE database includes the details of sales for each farm commodity in a given year to downstream processors, households and exports, plus the value of sales of competing imports to each user. The database weights and various model parameters determine the total elasticity of demand for each farm output. Although much of Australia's agriculture is export oriented, drought-induced inward supply shifts reduce export supplies and thereby lower the total elasticity of demand for farm commodities by increasing the domestic share of total sales. Moreover, drought also increases demand for grains and hay as livestock feed, which pushes up local prices. Freight costs limit the extent to which farmers can purchase feed from distant sources. Imposing more elastic total demands on the model through higher import substitution parameters, higher export demand elasticities and higher expenditure elasticities (the latter in violation of Engel's law) may lead to flip-flop solutions and move us further away from realism.

2.2. The need to model excess capacity in downstream sectors

To find a way of depicting an extreme drought in a CGE model, we consider the impact of drought on downstream sectors. The ability of the downstream manufacturers to cope with lower supplies of inputs depends on a number of factors.

For example, while drought since 2006–07 has put dairy processors based in northern Victoria/southern New South Wales under financial pressure that led to cost cutting via such measures as retrenchments, there has been no substantial rationalisation of capacity to date. A number of factors have contributed to this. First, milk is produced Australia-wide, and processors have the option, although expensive, of transporting milk from non-drought-affected regions. For example, seasonal conditions were relatively favourable in northern New South Wales in 2007 and 2008, resulting in milk being transported south. As a means of reducing industry-wide transport costs, milk swaps between companies (where milk contracted to a given company is supplied instead to the nearest processor and swapped for milk elsewhere) have become commonplace. In addition, the changing feed-base away from irrigated pastures has lead to a flatter pattern of milk production through the year, favourable to the production of the high-valued cheese relative to milk powder. This flexibility in output mix has also helped maintain processor margins in the region.

[4] Dixon and Rimmer (2002, pp. 222–225) derive a formula for export demand elasticities based on import substitution equations. This formula makes such elasticities in a national model consistent with the Armington parameters in a global model such as GTAP.

Other industries do not have as many options. Whereas milk production out of the SMDB has fallen in the order of one-third since its peak in 2001–02, rice output has fallen by more than 90 per cent, with no potential to prop up capacity utilisation by transporting in raw product from elsewhere. The Deniliquin rice mill, previously the biggest rice mill in the southern hemisphere, closed in 2008. In November 2010, Sunrice (2010) announced that the mill would re-open in the coming months. With the return of average or above average rainfall and a restoration of irrigation water allocations, water has once again become cheap enough to enable significant levels of rice production.

A standard CGE model does not capture a reduction in capacity utilisation in downstream processing sectors in response to drought, instead solving for large inward farm supply shifts with consequent implausibly large farm output prices. Far from modelling a drought-induced regional recession, there is a danger that spurious terms-of-trade gains will dominate the scenario. This is not to say that farm output prices do not increase in response to drought. Rather, such price hikes tend to be small relative to output declines. Drought usually is a time of rural hardship, not of regional windfall gains.

In initial attempts to analyse the impact of the global financial crisis on the US economy, Dixon and Rimmer (2010) could not ascribe large inward macrodemand shifts to their model without a consequent large real depreciation. There were no observed large real exchange rate adjustments to the US economy during the crisis. In response, the authors devised a mechanism to mimic excess capacity, motivated by the Keynesian theory of multiple equilibria, in which price adjustments alone will not dig an economy out of recession. The implementation of excess capacity solved the problem. By analogy, as the excess capacity mechanism choked off an unrealistic real depreciation in Dixon and Rimmer (2010), we felt that it could also subdue modelled farm output price hikes within TERM-H2O in an extreme drought simulation. That is, allowing excess capacity in downstream processing sectors would reduce their demand for farm inputs as the scarcity of inputs worsened owing to drought.

Dixon and Rimmer (2010) depicted excess capacity via a theory of sticky capital adjustment. The usual theory (i.e. constant returns) is that industries operate at full capacity, so that used capital ($KU_{jr,t}$ for industry j in region r and time period t) is equal to existing capital ($KE_{jr,t}$). With a sticky rental adjustment assumption, we can think of the rental rate as a profit markup on variable costs. This markup will adjust downwards slowly in response to excess capacity.

$$\left(\frac{R_{jr,t}}{Rf_{jr,t}} - 1\right) = \left(\frac{R_{jr,t-1}}{Rf_{jr,t-1}} - 1\right) + \alpha\left(\frac{KU_{jr,t}}{KE_{jr,t}} - 1\right) + S_{jr,t} \quad (1)$$

$$R_{jr,t} = f(KU_{jr,t}) \quad (2)$$

In Equation (1), $R_{jr,t}$ and $Rf_{jr,t}$ are the rental rates for industry j in region r and year t in the respective policy and forecast runs.[5] $S_{jr,t}$ is a slack variable, which implements Equation (1), and α a positive parameter. Equation (2) is the capital demand equation in which f is a decreasing function of $KU_{jr,t}$. During drought, we invoke the sticky rental adjustment mechanism for downstream processing industry j (i.e. $S_{jr,t} = 0$). This means that used capital $KU_{jr,t}$ falls relative to existing capital $KE_{jr,t}$. Instead of responding to reduced farm output by paying much higher input prices, processors reduce capital utilisation. This is equivalent to an inward movement in processing supply curves and an accompanying reduction in demand for farm inputs. While this will have little impact on processing sector output prices, it will reduce the demand for and moderate scarcity-induced price hikes of farm inputs and consequently moderate the fall in the rate of return on capital in the processing sector. In turn, smaller farm output price hikes will moderate terms-of-trade effects in small regions during drought. When better seasons return, the industry resumes full capacity utilisation. In the full capacity state, $S_{jr,t} \geq 0$ and $KU_{jr,t} = KE_{jr,t}$. The change of state between full capacity (with market-clearing rate-of-return adjustments) and excess capacity (a quantity adjustment) requires the use of a complementarity condition, implemented in the model using GEMPACK software, as described by Harrison *et al*. (2004).

Why did we not model excess capacity via the inclusion of fixed costs? A number of CGE applications have, including Harris (1984), Abayasiri-Silva and Horridge (1998), and other studies downloadable from the GTAP website: Kharitonov and Walmsley (2004), Kuik and Gerlagh (2005) and Hertel and Swaminathan (1996). Applications that include fixed costs in the model formulation typically apply to relatively small change cases. The inclusion of fixed costs would have further complicated TERM-H2O without guaranteeing a solution in large change simulations. Instead, we followed Dixon and Rimmer (2010), who accepted excess capacity as a real-world phenomenon. Their method concentrates on obtaining a plausible model solution in a large change case without attempting to explain excess capacity.

3. Drought in south-eastern Australia from 2006–07 to 2008–09

Bureau of Meteorology data indicate that the entire SMDB basin had either decile one rainfall or the lowest on record for the 3-year period between January 2006 and December 2008 (see Footnote 1). Recurrent droughts affected both dry-land and irrigated production. Dry-land production was most adversely affected in 2006–07 and 2007–08, with a partial recovery in some regions in 2008–09. For irrigators, the impacts of catchment shortfalls on water allocations continued until the flood events of 2010–11. Table 2 shows

[5] In dynamic modelling, we run a baseline forecast and a policy run. In the case of an adverse event such as drought, the 'policy' run is more accurately labelled the 'perturbation' run.

the modelled percentage shortfalls in water availability by region for 2007–08. We use TERM-H2O with a theory of sticky capital adjustment in some downstream processing sectors to simulate drought impacts. The exogenous policy shocks are the estimated direct impacts on both dry-land productivity and irrigation water allocations from 2006–07 to 2008–09, with an assumed recovery in dry-land productivity in 2009–10 and eventual full recovery in water allocations by 2011–12 (the modelling was completed before the floods of 2010–11).

3.1. Comparing naïve calculations and modelled impacts for 2007–08

We start with an analysis of our results for 2007–08. Lack of rainfall in 2007–08 meant that dry-land productivity in the SMDB was below average. Irrigation allocations were at a low point after two successive years of drought.

We can calculate a naïve or first-guess estimate of the contribution of a farm subset k of all industries j to a percentage change in GDP in region r (gdp_r) as:

$$\text{gdp}_r = \sum_k (\text{PRIM}_{kr}.\text{q}_{kr}) \Big/ \sum_j \text{PRIM}_{jr} \tag{3}$$

PRIM is the level of value-added output of each sector, and q is the percentage change in output. As a starting point for our naïve calculation, we assume that for irrigation sectors i, $\text{q}_i = \text{xwat}_i$ where the latter is the percentage difference in water allocations from normal. Additionally, our naïve calculation of lost output in dry-land sectors j equals the technological deterioration owing to drought (aprim_j) so that $\text{q}_j = \text{aprim}_j$. Our initial estimate of the impact of drought in which a refers to all industries in region r is:

$$\text{gdp}_r = \left[\sum_{\text{i}} (\text{PRIM}_{\text{ir}}.\text{q}_{\text{ir}}) + \sum_{\text{j}} \left(\text{PRIM}_{\text{jr}}.\text{q}_{\text{jr}}\right)\right] \Big/ \sum_a \text{PRIM}_{ar} \tag{4}$$

In Table 2, row (1) shows dry-land productivity and row (2) an index of water availability relative to a normal year. Rows (3–5) provide estimates of the contributions of dry-land plus irrigation farming to GDP in each region. Rows (6–8) contain our first-guess contributions of irrigation and dry-land sectors to changes in real GDP in the regions of SMDB. The modelled contributions to changes in regional GDP by broad sector and irrigation water are shown in rows (9–14). Row (15) shows the volume of net water sold by region.

If there were no movements of farm factors including water between sectors, the first-guess impacts on farm sectors shown in rows (6) and (7) would equal the TERM-H2O impacts shown in rows (9) and (10) of Table 2. This would be equivalent to CET parameters for farm sectors being set to zero, with zero substitutability between water and other primary factors. Comparing rows (6) and (9), we see that dry-land first-guess losses predict modelled broad sectoral losses quite closely in some, but not all, regions. Variations arise from some resource movements. In Lower Murrumbidgee, farm factors move from irrigated towards dry-land production as irrigation water is exported to other regions.[6] Note that although the contribution of water to regional GDP increases during drought, as its demand is inelastic and therefore its value rises as its availability falls, the contribution to real GDP of water trading is zero. That is, we see the benefits of water trading by comparing the final column entries for rows (10) and (7) in Table 2. Due substantially to water trading (and to a lesser extent, factor substitution away from water), the contribution of irrigation sectors to real GDP in SMDB is −1.9 per cent instead of −3.4 per cent as given by the first-guess calculation.

As mentioned, by comparing rows (9) and (10) with rows (6) and (7) in Table 2, we see the impact of imposing non-zero farm factor CET and CES parameters (and water trading) on the results. What difference would altering the parameters make to results? Our experience with TERM-H2O is that the most important modification necessary to capture observed movements of water as water scarcity changes or relative farm output prices change is the inclusion of CET farm factor movements. Moving from full trading in the SMDB to no inter-regional trading tends to have a bigger impact than parametric variation (within reasonable limits), especially if there are pronounced differences in water allocation shortfalls and productivity losses between regions. Rather than present results of parametric variation here, we instead compare modelled results with actual ABS data later in this section.

We might expect modelled GDP losses in each region to be somewhat larger than our naïve calculation of losses. This is through negative impacts on downstream sectors and the impact of reduced household consumption on service sectors in each region. Modelled GDP losses are larger than our first-guess calculation of losses for some but not all regions shown in Table 2. Water trading between sectors and regions, combined with mobility of farm factors, alleviates some of the losses. For example, Lower Murrumbidgee is a substantial exporter of water to other regions in the drought years of the scenario. The movement of factors including water partly offsets productivity losses and water allocation shortfalls, so that the modelled GDP loss is smaller than the first-guess calculation of the GDP loss in this region. Changes in output by sector in part reflect differences in water's share of total costs, but are also influenced by different demand elasticities and input-substitution possibilities. For example, the dairy and other livestock sectors can substitute between land and cereal inputs.

Finally, in Table 2, we see that the impacts on downstream sectors, although negative, do not imply large regional multipliers. Regional aggregate consumption falls relative to forecast owing to drought. In the short term,

[6] The solution procedure is Euler 60-steps (and Euler 256-steps in the first 4 years of drought and recovery), used to eliminate solution errors from the linearised model in this large change simulation (Dixon *et al*. 1982, chapter 5).

Table 2 Impacts of drought by region, 2007–08 relative to no-drought baseline (%)

	WagCntMrmNSW	LMrmbNSW	AlbUpMrryNSW	CentMrryNSW	MrryDrlngNSW	MldWMaleeVic	EMalleeVic	NthLoddonVic	SthLoddonVic	ShepNGoulVic	SSWGlbrnVic	OvnsMurryVic	MurrayLndsSA	All SthMDB
Water allocations and productivity levels (100 = average)														
(1) Dry-land productivity*	42	42	42	42	42	36	36	69	69	69	69	69	36	51
(2) Water†	51	51	14	14	40	42	42	46	40	46	46	45	60	44
Contributions to GDP in 2005–06 base (%)														
(3) Dry land	8.3	8.4	6.4	2.3	8.0	13.6	14.4	3.9	1.4	6.9	7.4	3.8	8.0	6.8
(4) Irrigation	1.9	15.3	1.2	19.6	12.1	8.0	14.5	1.5	0.7	9.2	3.2	2.8	14.1	6.1
(5) Total	10.2	23.7	7.6	21.9	20.1	21.6	28.9	5.4	2.1	16.1	10.6	6.6	22.1	12.9
Naïve estimates of contributions to GDP (%)														
(6) Dry land	−4.8	−4.9	−3.7	−1.3	−4.6	−8.7	−9.2	−1.2	−0.4	−2.1	−2.3	−1.2	−5.1	−3.3
(7) Irrigation	−0.9	−7.5	−1.0	−16.9	−7.3	−4.6	−8.4	−0.8	−0.4	−5.0	−1.7	−1.5	−5.6	−3.4
(8) Total	−5.7	−12.4	−4.7	−18.2	−11.9	−13.3	−17.6	−2.0	−0.9	−7.1	−4.0	−2.7	−10.8	−6.7
Modelled contributions by broad sector														
(9) Dry land	−4.4	−2.6	−3.1	0.1	−3.0	−9.0	−9.2	−0.7	−0.3	−0.9	−1.4	−0.8	−5.6	−2.7
(10) Irrigation	−1.0	−10.2	−0.3	−13.2	−2.0	−1.1	−0.5	−0.5	−0.1	−2.1	−1.0	−0.8	−0.5	−1.9
(11) Food	−0.3	−0.6	−0.1	−0.2	0.0	−0.1	−0.2	−0.4	−0.1	−0.7	−0.1	−0.2	−0.6	−0.3
(12) Rest	−1.1	−0.5	−0.7	−1.6	−0.6	−1.7	−1.3	−0.2	−0.3	−0.6	−0.4	−0.9	−0.9	−0.8
(13) Net Water	0.4	3.8	−0.2	−4.9	−1.5	−0.7	−1.6	0.1	0.0	0.6	0.3	−0.2	−0.7	0.0
(14) GDP	−6.4	−10.0	−4.4	−19.7	−7.1	−12.7	−12.8	−1.6	−0.7	−3.6	−2.6	−2.8	−8.3	−5.7
(15) Net water sold (GL)	83	456	−38	−194	−33	−29	−86	5	−4	−104	2	−20	−39	0

*Authors' estimates based on rainfall deficiencies.
†Data provided by Murray-Darling basin Authority.

when housing stocks, for example, are fixed most adjustment is going to be on housing rentals. Prolonged adverse conditions in MDB regions would lead to long-run quantity adjustments in housing and enlarged negative multipliers overall, but in the short term, price adjustments reduce the size of multipliers driven by the spending effect.

Table 3 compares modelled outcomes for farm products in the SMDB with available data on observed changes. Columns (1–3) show the modelled deviations from forecast owing to drought (versus a hypothetical no-drought baseline for 2007–08), and columns (4–6) estimated actual changes from 2005–06 to 2007–08. Hence, the comparisons are not between like and like, but are the best we can do.

Cereal production did not shrink as much in the observed period as we modelled. This reflects soaring cereal prices in the observed period: the actual price increase was twice the modelled drought-induced price increase. World prices of cereals in 2006–07 were driven up by increased use of bio-fuels and other international developments beyond price increases arising from drought within Australia. The output outcomes for dairy cattle, grape and fruit turned out better than we modelled, again with observed prices rising more than the modelled deviation. Yet, dairy cattle's use of water dropped more than we modelled: this reflects a larger than modelled movement from irrigated to dry-land production. As dairy output prices were high in 2007–08, dairy producers were willing to move to dry land and pay for cereal feed (grains and hay). Although the observed value of dairy cattle output rose by 1.9 per cent (Table 3, column (4)), the value added almost certainly dropped significantly, reflecting high feed costs and bringing the observed

Table 3 Comparing modelled southern Murray-Darling basin outcomes to observed changes

	Modelled outcome deviation from 2007–08 base (%)			Observed 2007–08 relative to 2005–06 (%)		
	Output*	Price	Water used†	Output‡	Price	Water used†
	(1)	(2)	(3)	(4)	(5)	(6)
Cereal	−55.3	43.6	−78.8	1.1	92.1	−55.9
Rice	−84.9	86.2	−90.7	−98.2	46.3	−97.8
Dairy cattle	−13.6	29.5	−40.9	1.9	52.0	−64.9
Other livestock	−23.1	41.4	−44.6	na	na	−76.8
Grapes	−17.9	18.0	−49.0	2.2	44.6	−14.4
Fruit	−7.7	13.5	−23.1	5.4	17.6	−17.8
Vegetables	3.5	6.8	−1.4	−2.0	3.1	−15.5
Other agriculture	17.3	7.9	12.6	na	na	−50.0

*Value-added basis.
†Water used in irrigation production.
‡Value of output, not value added.
Source: ABS (Australian Bureau of Statistics) (2009b); Anderson *et al.* (2010); ABARE (Australian Bureau of Agricultural and Resource Economics) (2009).

result closer to the modelled result. Overall, there was a greater movement of water out of rice production than we modelled.

Other than rice (for which the commodity price hike was smaller than modelled), only vegetables and the relatively small other agriculture sector did worse than modelled. Observed vegetables output did marginally worse than the modelled outcome because of the observed output price hikes of competing more export-oriented products. The other agriculture sector includes nursery products: Australia's mainland capitals with the exception of Darwin all faced water restrictions in this period, which drove down demand for this sector from household gardeners.

Next, we examine water prices. We would expect water prices to have increased between 2005–06 and 2007–08 by a larger amount than modelled, because of the observed surge in commodity prices for some major irrigation products. This is so: the modelled increase was \$285 per megalitre relative to forecast in 2007–08, compared with an observed increase in the Goulburn region relative to 2005–06 of around \$500 per megalitre. A weakening of commodity prices in 2008–09 resulted in the price of water falling to \$275 per megalitre above 2005–06 levels, closer to the modelled outcome (Watermove weekly data, downloaded from http://www.watermove.com.au, authors' calculations).

The Australian Water Market Report for 2007–08 shows an observed pattern of net downstream trade (National Water Commission 2009). Small amounts were transferred out from the upper Murray reaches in both NSW and Victoria (that is, the Ovens-Murray and Albury-Upper Murray regions, Figure 1), and larger amounts from the Goulburn and lower NSW Murray reaches. The largest net seller was the Murrumbidgee valley, reflecting the influence of rice. Rice is grown in better years; however, a moderate worsening of water scarcity is sufficient to make it more profitable for growers to sell their water allocation for a year than to continue growing rice. The buyers of water were the Victorian Mallee regions and most notably South Australia. In terms of how the modelling replicated this pattern, the main differences are that the model projected higher than observed net water exports from the Murrumbidgee regions and lower than observed net imports to South Australia. The latter was because partly of purchases by the South Australian government. In 2008–09, the observed pattern of water trading moved closer to that modelled by TERM-H2O. The Ovens-Murray region became a net importer of water as modelled (Table 2, row (14)).

3.2. Dynamic analysis of drought followed by a prolonged recovery

Our simulation consists of widespread drought conditions from 2006–07 to 2008–09, with a dry-land recovery in 2009–10 but some delay before the restoration of full water allocations for irrigation sectors. As shown in Table 3, real GDP in SMDB fell 5.7 per cent below forecast in 2007–08 owing to

Figure 1 Map of southern Murray-Darling basin regions in TERM-H2O. Regions: 1 Wagga-Central Murrumbidgee, 2 Lower Murrumbidgee, 3 Albury-Upper Murray, 4 Central Murray, 5 Murray Darling, 7 Far West, 6 Rest of VIC, 7 Mildura-West Mallee, 8 East Mallee, 9 Bendigo-Nth Loddon, 10 Sth Loddon, 11 Shepparton-Nth Goulburn, 12 Sth/SthWest Goulburn, 13 Ovens-Murray14 QLD, 15 Rest of SA, 16 Murray Lands SA, 17 Rest of Australia, 18 Rest of NSW.

drought. The simulated outcome for 2009–10 remains below forecast because of irrigation water not being fully restored (Fig. 2).

In subsequent years, as a consequence of sharp falls in investment during the drought years, aggregate capital stocks persist below forecast (−0.12 per cent in 2017–18). Similarly, employment does not recover fully in the simulation period. SMDB employment fell to 1.3 per cent below forecast in 2007–08, equivalent to 6000 jobs. Even in 2017–18, long after the recovery, employment persists at 0.36 per cent (around 1500 jobs) below forecast.[7]

Figure 3 shows the impact of drought on downstream processing sectors in SMDB. In the initial year of drought (2006–07), capital stocks do not change in response to drought. They are pre-determined by the link between current period capital stocks, lagged capital stocks net of depreciation and lagged investment. However, by introducing a theory of excess capacity to the

[7] National employment is exogenous in the policy simulation. Regional labour markets follow the national wage, so that all regional adjustments are via labour movements rather than regional wage differentials. Another version of dynamic TERM includes a theory of regional sticky wage adjustment (Wittwer *et al.* 2005).

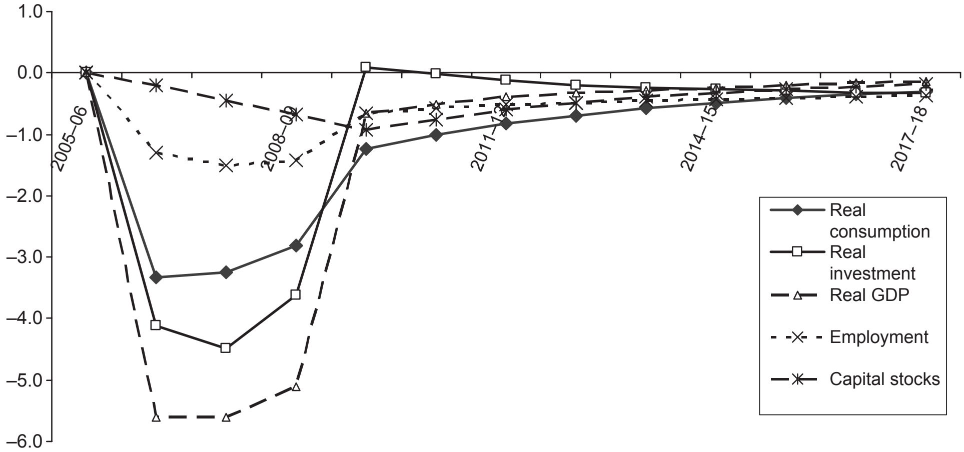

Figure 2 Macro-economic outcomes for southern Murray-Darling basin (% deviation from forecast).

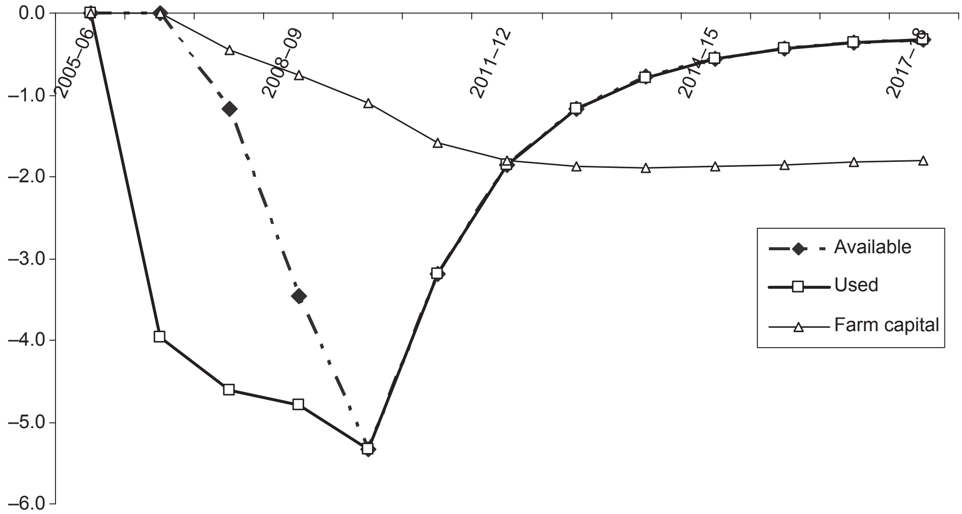

Figure 3 Downstream processing and farm capital, southern Murray-Darling basin (SMDB) (% deviation from forecast). Used and available capital in SMDB for the aggregate of meat products, dairy products, wine & other beverages and flour & processed cereals.

model, we allow a temporary gap to occur between available and used capital for downstream processing sectors. This gap gradually closes between 2006–07 and 2008–09 as falling investment erodes the capital base. With a substantial recovery in 2009–10, the gap is eliminated and the usual theory of constant returns to scale is resumed within the model. The prolonged drought and irrigation water allocation shortfalls have a negative impact on farm investment, so that farm capital persists at almost 2 per cent below forecast in 2017–18.

4. Conclusions

The significant contribution of this study is to model very large inward supply shocks to estimate the impact of drought in the SMDB on regional economies. Drought is an inevitable part of farming, but few studies report on the economy-wide modelling of drought impacts. Modellers face obstacles in reaching realistic solutions in drought simulations. In TERM-H2O, it is necessary to introduce excess capacity to downstream processing sectors to keep farm output price hikes within realistic bounds in response to drought-induced shrinkages in farm supplies.

The main finding of this study is that in the short term, drought across the SMDB reduces employment relative to forecast by around 6000 jobs. Even after a return to average seasons, the impacts of drought remain. Depressed farm investment during drought results in farm capital persisting below baseline levels, even many years after drought has ended. Consequently, employment in SMDB does not return to baseline levels but remains at 1500 jobs below forecast in 2017–18. The same model indicated only modest job losses in SMDB arising from increased environmental flows implemented through buyback (Dixon *et al*. 2011). No other model used to estimate the regional employment consequences of buyback or similar policy proposals has been tested in a drought scenario.

It is possible to check some results against actual outcomes. TERM-H2O results relative to forecast for 2007–08 give a reasonable account of observed changes from 2005–06 to 2007–08. Most differences between modelled and observed outcomes arise from global conditions that were not included in the drought scenario. For example, world grain and dairy output prices rose strongly in 2007–08. For these commodities, TERM-H2O predicted a larger decline in output and smaller hike in prices than observed. Consequently, TERM-H2O underestimated the dollar per megalitre rise in the price of irrigation water for 2007–08, yet tracked the irrigation water price reasonably in 2008–09 when grain and dairy prices fell.

At the sub-state level, data on employment numbers are harder to obtain between censuses. The ABS conducts the Labour Force Survey regularly but data are state-wide estimates. Beyond anecdotes and other employment estimates that are certain to be patchy rather than comprehensive, a better picture of the impact of drought on SMDB may have to wait until small region employment by industry numbers appear after the 2011 census.

It appears highly probable that as the current policy of purchasing water from farmers for environmental flows continues in the Murray-Darling basin, the claims of thousands of job losses arising from the policy will not stand up to scrutiny. Even using a simple calculation based on farm shares of regional GDP, the regional economic impacts of drought are many-fold worse than the probable impacts of water buybacks. It is possible that a high Australian dollar will impose greater difficulties on SMDB farmers in the present decade than either drought or water buyback policy.

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