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Closing the factory doors until better times: CGE modelling of drought using a theory of excess capacity

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Abstract

The aim of this paper is to analyse the regional economic impacts of a prolonged period of recurrent droughts. The model used for analysis is TERM-H2O, a dynamic successor to the bottom-up, comparative static TERM (**T**he **E**normous **R**egional **M**odel). We concentrate on the regions of the southern Murray-Darling basin (SMDB).

Large change simulations are a challenge for modellers. Drought brings substantial inward supply shifts for farm sectors. This paper outlines various theoretical modifications undertaken to improve the modelling of drought in a computable general equilibrium (CGE) framework and then applies them to the period from 2005–06 on. In particular, we apply a theory of sticky capital adjustment to downstream processing sectors, whereby processors retire capital temporarily in response to scarcer farm products. This limits upward price movements in farm outputs and results in more realistic modelling of drought.

Results are explained using a back-of-the-envelope approach. 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.

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Introduction

South-eastern Australia has endured recurrent droughts since that of 2002–03. The 2002–03 drought impacted mainly on dry-land farm production, with the exceptions of the Goulburn Valley and Murrumbidgee irrigation regions. This meant that the negative impacts of drought were extensive in dry-land agriculture but limited in the irrigation sectors of the Murray-Darling basin. Subsequent droughts led to a worsening picture for irrigators. 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 (figure 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 aims to provide 100 percent allocations in 97 years out of 100 for the Goulburn system, but has failed to do so in five of the past eight irrigation seasons.

The aim of this paper is to analyse the regional economic impacts of this prolonged period of drought. The model used for analysis is TERM-H2O, a dynamic successor to the bottom-up, comparative static TERM (**T**he **E**normous **R**egional **M**odel) (Horridge *et al*., 2005; Wittwer *et al*., 2005; Wittwer 2009). We concentrate on the regions of the SMDB. This paper outlines various theoretical modifications undertaken to improve the modelling of drought in a computable general equilibrium (CGE) framework and then applies them to the period from 2005–06 on.

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 percent (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 services sectors.

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). As this was the first drought for several years, irrigation water managers were able to maintain reasonable supplies of water to irrigators by drawing down reservoirs with the expectation of better seasons and restorative water yields ahead. From the perspective of CGE modelling, there appeared to be little need at this stage to distinguish between irrigation and dry-land activities, or to account for irrigation water availability. Even so, the original TERM model underestimated the compositional change of farm sector outputs, notably in tracking observed reductions in rice and cotton outputs. Subsequent model enhancements on the supply side have addressed this.

Another problem in modelling the 2002–03 drought was that TERM initially predicted unrealistically large endogenous price changes for farm outputs. For sectors such as dairy, total demand appeared to be too inelastic, resulting in percentage changes in prices far exceeding percentage changes in output. That is, we modelled drought as having a positive impact on the revenue of farmers. The introduction of a small "alchemy" parameter (that is, an intermediate input substitution parameter), alleviated upward price pressures to a moderate extent in response to inward farm supply shifts.

The large price changes could also be attributed to the degree of model aggregation. The original aggregation covered 45 regions, at the statistical division in farm regions, with some composite regions elsewhere. Initially, the sectoral representation was relatively coarse, in order to keep the model database within usable dimensions. This made the demand for some farm products more inelastic than otherwise. For example, dairy cattle output (farm milk) is sold almost exclusively to the dairy products sector. If we represent dairy products only in a coarsely aggregated food products sector, dairy cattle's input cost share in broad food production is smaller than its cost share in dairy products. The smaller is the cost share, the more inelastic the demand for an input. Further disaggregation enhanced the realism of the modelled price impacts. After overcoming troubling aspects in implementation of the first TERM simulation, the authors predicted with reasonable accuracy agriculture's changing share of state GDP as revealed by subsequent state accounts data (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. 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. To place into perspective how responsive water usage in rice production is to changes in water scarcity, water usage in the Murray-Darling basin dropped by 29 percent from 2001–02 to 2002–03, yet usage for rice production in the region dropped by 70 percent (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.

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

	2001–02	2002–03	2003–04	2004–05	2005–06
Water consumption (GL)					
Livestock pasture	2,971	2,343	2,549	2,371	2,571
Rice	1,978	615	814	619	1,252
Cereals (excl. rice)	1,015	1,230	876	844	782
Cotton	2,581	1,428	1,186	1,743	1,574
Grapes & fruit	868	916	871	909	928
Vegetables	152	143	194	152	152
Other agriculture	504	475	596	564	460
Total Agriculture	**10,069**	**7,150**	**7,087**	**7,204**	**7,720**

Source: ABS (2009a), table 4.20.

In order to make demand for water by users such as rice sufficiently elastic to track observed changes in usage, theoretical modifications were made to TERM on the supply side (Dixon, *et al.* 2010). The revised model (referred to hereafter as TERM-H2O) included the following:

- a split in most farm sectors between irrigated and dry-land technologies;
- three types of farm land, irrigated land, irrigable land (that is, land that becomes irrigated when water is applied to it) 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 or different dry-land sectors. Specific capital is immobile between sectors, reflecting the relative inflexibility of perennial cropping or livestock production. 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. Figure A1 outlines the theory of farm factor mobility in TERM-H2O.

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.

But while at the coarser regional representation, the 'alchemy' parameter and a finer sectoral representation were sufficient to limit the impacts of drought on farm output prices, the finer regional representation exacerbates this problem once again. The statistical division level tends to include regions dominated in economic structure by large towns. This makes these regions more service-intensive and less agriculture-intensive than is the case for rural regions at the SSD level.[1] 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

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[1] For example, farm income in the Murray statistical division in the 2006 TERM database accounted for around 12 percent of total regional income. One town, Albury, accounts for 40 percent of the population of Murray (ABS 2009b). Within the Murray statistical division, the agricultural share of GDP excluding Albury SSD (i.e., the Central Murray and Murray-Darling statistical sub-divisions) exceeds 20 percent.

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 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 (inter-regional plus international) which are included in GDP but not consumption. Regional imports are included in household consumption but not GDP. Therefore, terms-of-trade impacts raise the ratio of real consumption relative to real GDP. There is a danger of modelling real consumption gains in small regions in times of drought. Rectifying this requires a further theoretical modification.

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, though 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 after drought in 2006, 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.

Other industries do not have as many options. Whereas milk production out of the southern Murray-Darling basin has fallen in the order of one-third since its peak in 2001-02, rice output has fallen by around 90 percent, 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 indefinitely late 2007, along with others through the region.

A standard CGE model does not capture a reduction in capacity 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.

The challenge in a dynamic model is to model a temporary reduction in capital utilisation in response to drought. If capital were destroyed in order to mimic reduced capacity utilisation, then to maintain the dynamic link between investment and capital stocks, it would have to be rebuilt via investment. We believe it is more realistic to model a temporary retirement of processing capacity in response to drought, where it is possible to restore capital to full usage

without incurring investment costs or lags between investment and operational capital. For that, we require a modelling mechanism that permits a temporary reduction in utilisation in response to deteriorating economic conditions, followed by a return to full capacity with subsequent recovery.

Dixon and Rimmer (2009) implemented a theory of sticky capital adjustment as follows. The usual theory is that industries operate at full capital, so that used capital ($KU_{jr,t}$) 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.

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

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

In (1), $R_{jr,t}$ and $Rf_{jr,t}$ are the rental rates for industry j in region r and year t in the policy and forecast runs.[2] $S_{jr,t}$ is a slack variable which implements (1) and α a positive parameter. (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 utilization. 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).
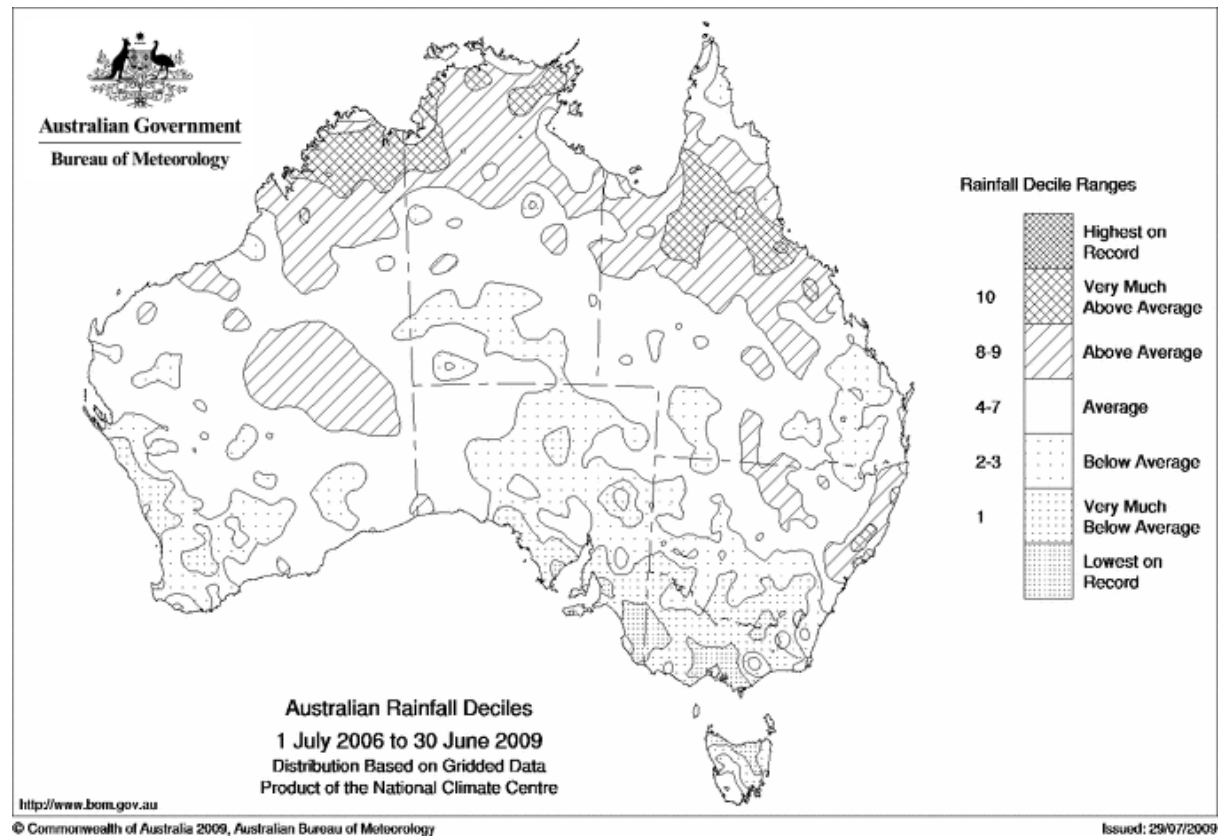
Drought in south-eastern Australia from 2006–07 to 2008–09

Unlike the drought of 2002–03, which was more widespread, the more recent droughts have had extreme, prolonged impacts concentrated on catchments in the SMDB. Bureau of Meteorology data indicate that the entire SMDB basin had either decile 1 rainfall or the lowest on record for the three-year period between July 2006 and June 2009 (figure 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 are likely to continue for several years after a seasonal recovery. Figure 2 shows 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 for 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. That is,

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[2] In dynamic modelling, we run a baseline forecast and a deviation-from-forecast or policy run. In the case of an adverse event such as drought, the "policy" run is more accurately labelled the "perturbation" run.

whereas in 2002-03, dry-land drought dominated the impacts, by 2009-10, dry-land productivity has returned to normal while water allocations to irrigators remain below normal.

Figure 1: Rainfall deficits for the three years to June 2009

Source: ftp://ftp.bom.gov.au/anon/home/ncc/www/rainfall/decile/36month/blkwht/history/nat/2006070120090630.gif

Comparing back-of-the-envelope 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. Crop yields were similar to 2006–07, which also suffered from a rainfall deficit. Irrigation allocations were at a low point after successive droughts, with further cuts relative to the previous year in most irrigation regions.

We can calculate a back-of-the-envelope (BoTE) 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:

$$gdp_r = \Sigma_k(PRIM_{kr}.q_{kr})/ \Sigma_j PRIM_{jr} \qquad (1)$$

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

$$gdp_r = [\Sigma_i PRIM_{ir}.q_{ir} + \Sigma_j PRIM_{jr}.q_{jr}]/ \Sigma_a PRIM_{ar} \qquad (2)$$

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In Table 2, row (1) shows dry-land productivity and row (2) an index of water availability relative to a normal year. Rows (3) to (5) provide estimates of the contributions of dry-land plus irrigation farming to GDP in each region. Rows (6) to (8) contain BoTE 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) to (14). Row (15) shows the volume of net water sold by region.

Dry-land contributions make a substantial contribution to overall real GDP losses in most regions. When we compare row (6) with (9) in table 2, we see that dry-land BoTE losses predict modelled 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.[3] 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.

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[3] The solution procedure is Euler 60-steps (and Euler 235-steps in the first four 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). The database is updated at the end of each step, so that if value weights change, dry-land modelled outcomes may vary from our BoTE estimate.

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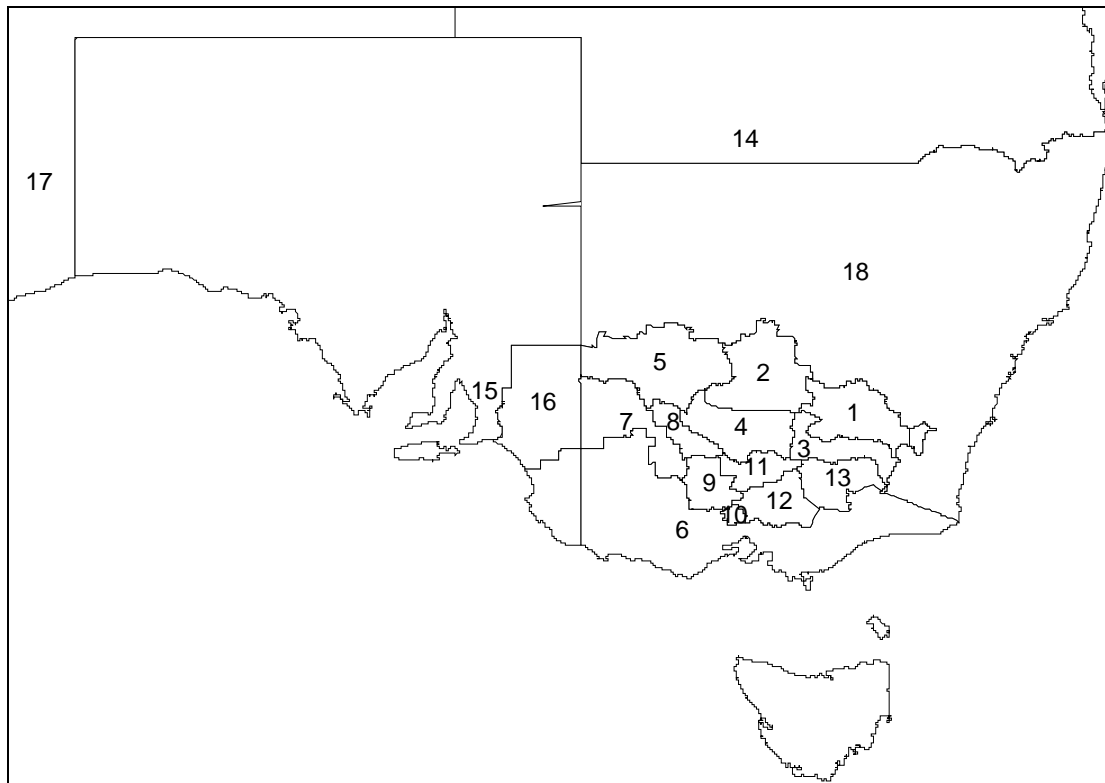
Regions: 1 Wagga-Central Murrumbidgee, 2 Lower Murrumbidgee, 3 Albury-Upper Murray, 4 Central Murray, 5 Murray Darling, 7 Far West, 6 Rest of VIC, 7 Mildura-West Mallee, 8 East Mallee, 9 Bendigo-Nth Loddon, 10 Sth Loddon, 11 Shepparton-Nth Goulburn, 12 Sth/SthWest Goulburn, 13 Ovens-Murray14 QLD, 15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

We might expect modelled GDP losses in each region to be somewhat larger than BoTE 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 BoTE 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 and allocation losses, so that the modelled GDP loss is smaller than the BoTE GDP loss in this region.

Changes in output by sector in part reflect water requirements per dollar of value added, 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. Recall from Table 1 that in the drought of 2002–03, water consumption in irrigated cereal production increased. This was driven by increased demands for feed from Goulburn dairy farmers as water available in that region decreased. In our simulation, dry-land dairy and other livestock production fall by larger percentages than corresponding irrigated production (Table 3). Had dry-land cereal production fared relatively better than other sectors, cheaper than otherwise cereals might have induced movement in the opposite direction towards dry-land livestock production.

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 [a]	42	42	42	42	42	36	36	69	69	69	69	69	36	51
(2) Water [b]	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
Back-of-the-envelope 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	-2.8
(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	-2.1
(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	3.2	-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	-10.9	-4.4	-20.0	-7.1	-12.7	-12.8	-1.6	-0.7	-3.6	-2.6	-2.8	-8.3	-6.0
(15) Net water sold (GL)	83	456	-38	-194	-33	-29	-86	5	-4	-104	2	-20	-39	0

a Authors' estimates based on rainfall deficiencies.
b Data provided by Murray-Darling Basin Authority.

## 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. Full recovery of allocations occurs only in 2011–12.

We first examine the year-by-year regional impacts of the scenario on real GDP. Agriculture's share of GDP averages 12.9 percent across the SMDB (Table 2). In addition, downstream processing makes up an additional 6.8 percent of regional GDP (based on ABS 2006 census data). These shares imply that drought can still depress regional economies markedly, even with structural change over time that has reduced agriculture's share of national income to around 3 percent.

Figures 3 and 4 show that the prolonged drought had a severe effect on real GDP within the SMDB. The biggest losers in terms of real GDP were Mildura–West Mallee and East Mallee in Victoria and Central Murray in NSW. That a number of regions do worse in 2008–09 than 2007–08 reflects worsening shortfalls in irrigation allocations in 2008–09. Similarly, the

stepped recovery for some regions (e.g., Central Murray in Figure 4) reflects the gradual restoration of irrigation water allocations after a return to normal rainfall from 2009–10 on.

Figure 3: Impact of drought on real GDP in Victorian regions
% change relative to no-drought baseline
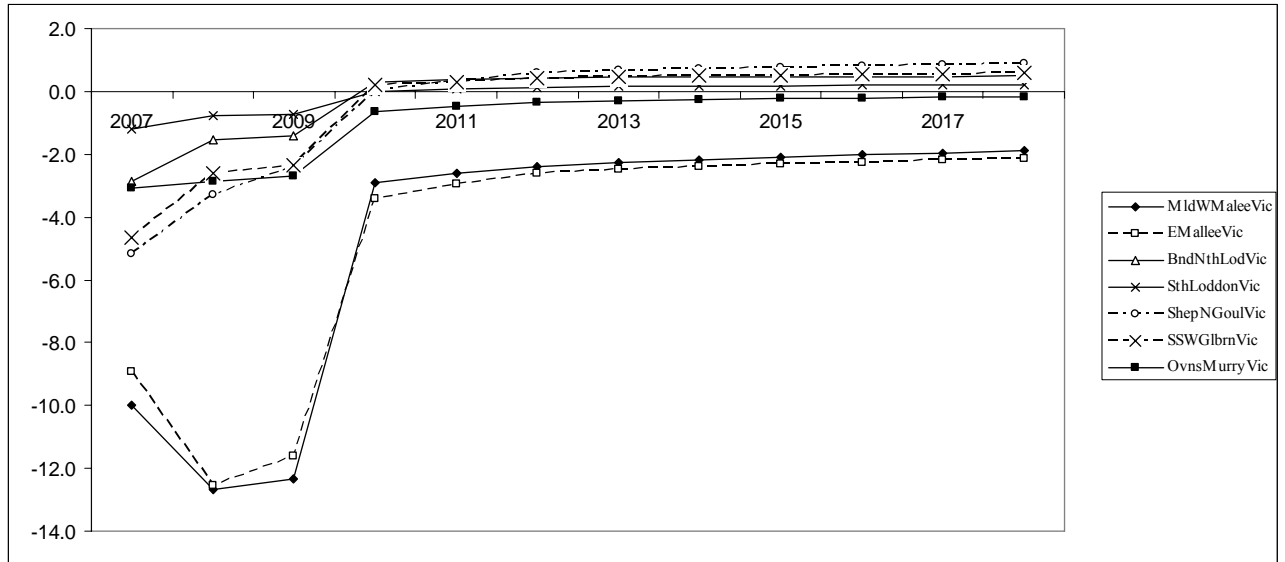
Regional employment (Figures 5 and 6) and capital stocks (Figures 8 and 9) are depressed by drought, but we expect percentage losses to be smaller than for real GDP, reflecting drought-induced technological deterioration rather than factor losses as the main contribution to income losses. As explained earlier, nominal consumption by region moves with nominal GDP, so that terms-of-trade movements will alter the real consumption to real GDP ratio. If the total elasticity of demand for farm products were larger, regional consumption losses would be larger. The elasticities are constrained by the requirements of domestic downstream processors, imperfect import substitution and finitely elastic export demand curves. Recall that one of the motivations for introducing excess capital to downstream users was to increase farm output demand elasticities so as to avoid excessive terms-of-trade impacts.

Figure 4: Impact of drought on real GDP in remaining Sth MDB regions
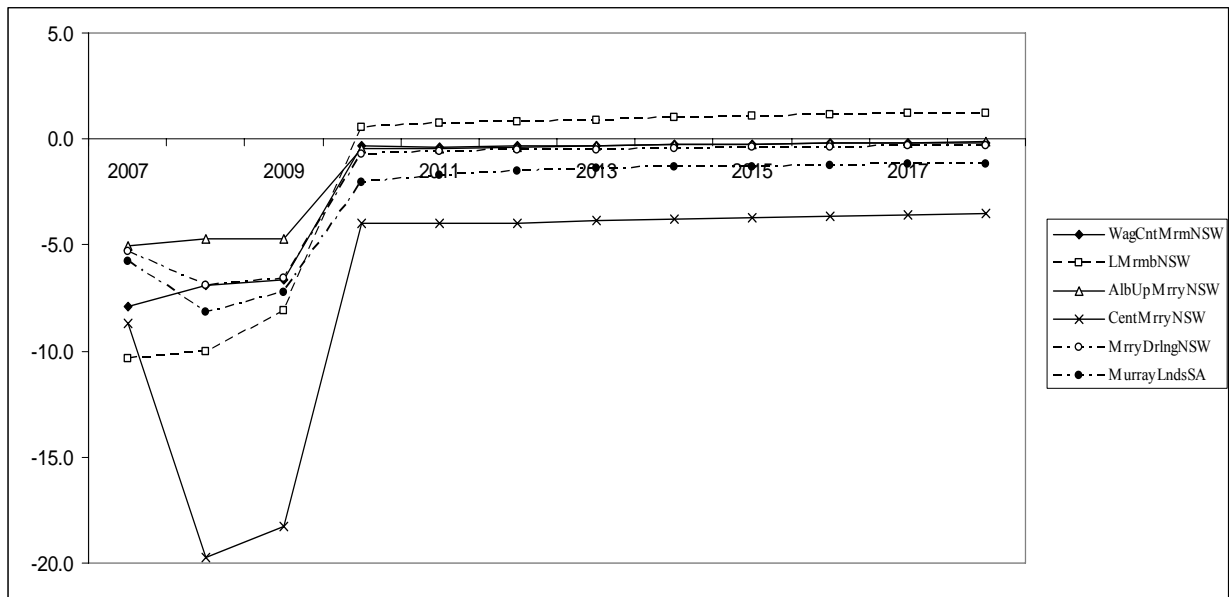% change relative to no-drought baseline

Figure 5: Impact of drought on employment in Victorian regions
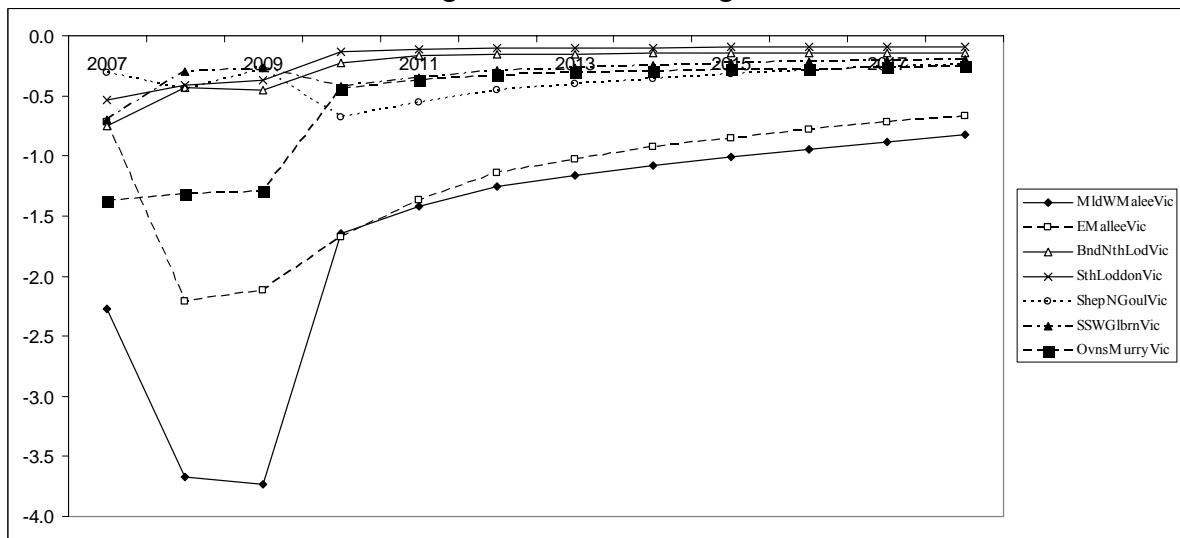% change relative to no-drought baseline

Figure 6: Impact of drought on employment in remaining Sth MDB regions
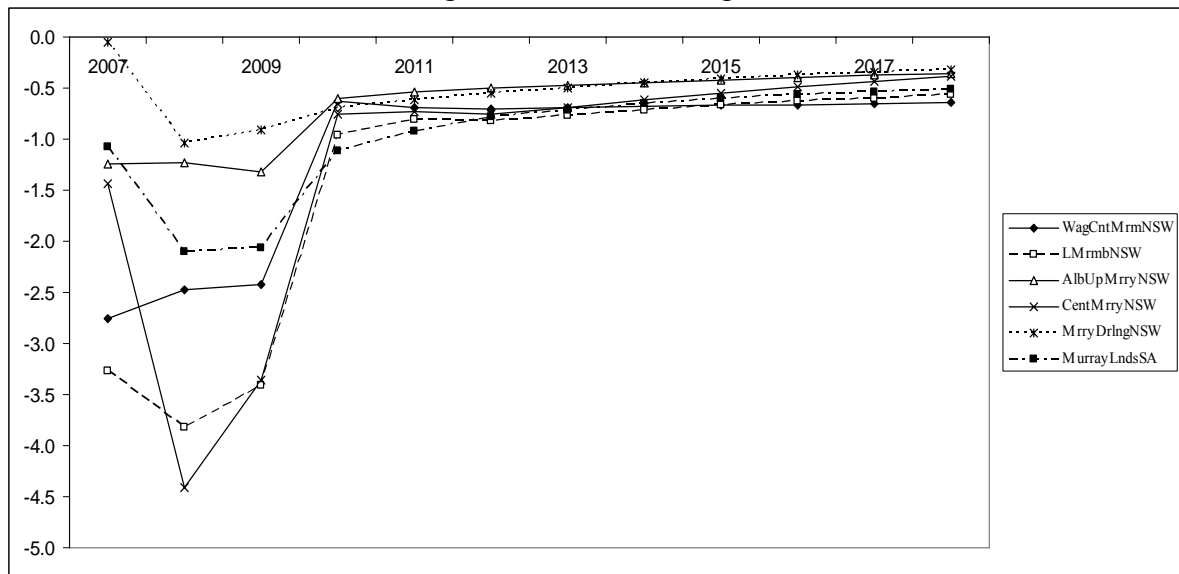% change relative to no-drought baseline

Figure 7 shows the difference between available and used capital in Shepparton-North Goulburn for meat products, dairy products and flour-cereals. These three industries include sticky capital, so that quantity adjustments occur in the form of changing capital utilisation as capital earnings decrease. That is, once there is a substantial recovery in seasons, which in turn lowers the price of farm inputs, the deviations in used and available capital merge. Note that in regions without sticky capital sectors, capital usage remains unchanged relative to forecast in the first year of the simulation, reflecting the lagged impact of changes in investment. Given this, we can deduce from Figures 8 and 9 that in addition to Shepparton-North Goulburn, Wagga-Central Murrumbidgee and Murray Lands include sectors with sticky capital, allowing deviations from forecast of used capital in the first year of the simulation.

Figure 7: Available and used capital in Shepparton-North Goulburn
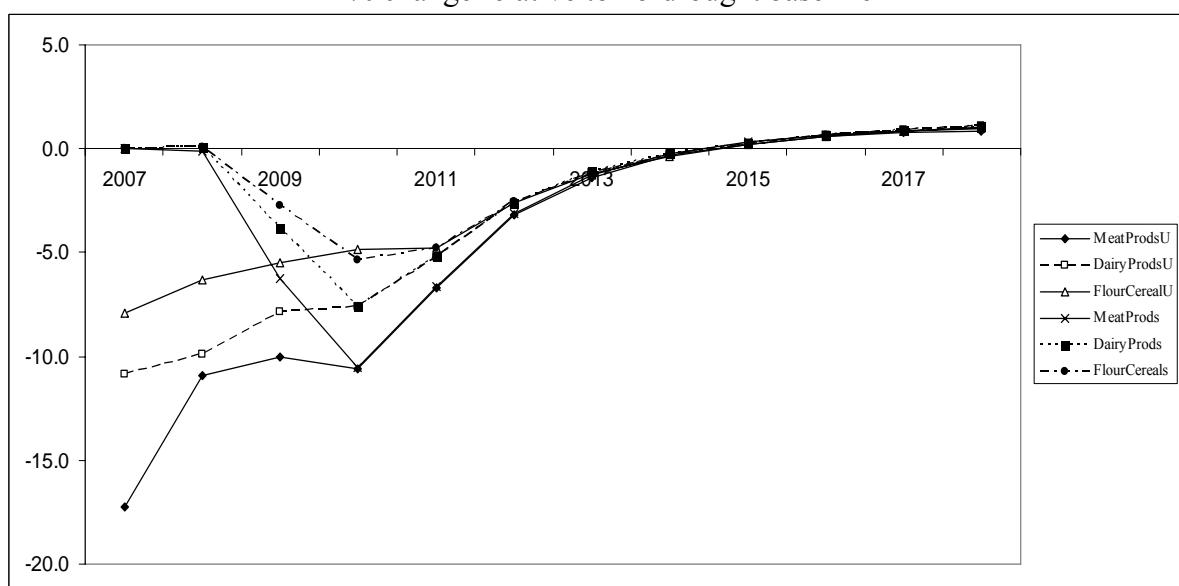% change relative to no-drought baseline

Figure 8: Impact of drought on capital stocks in Victorian regions
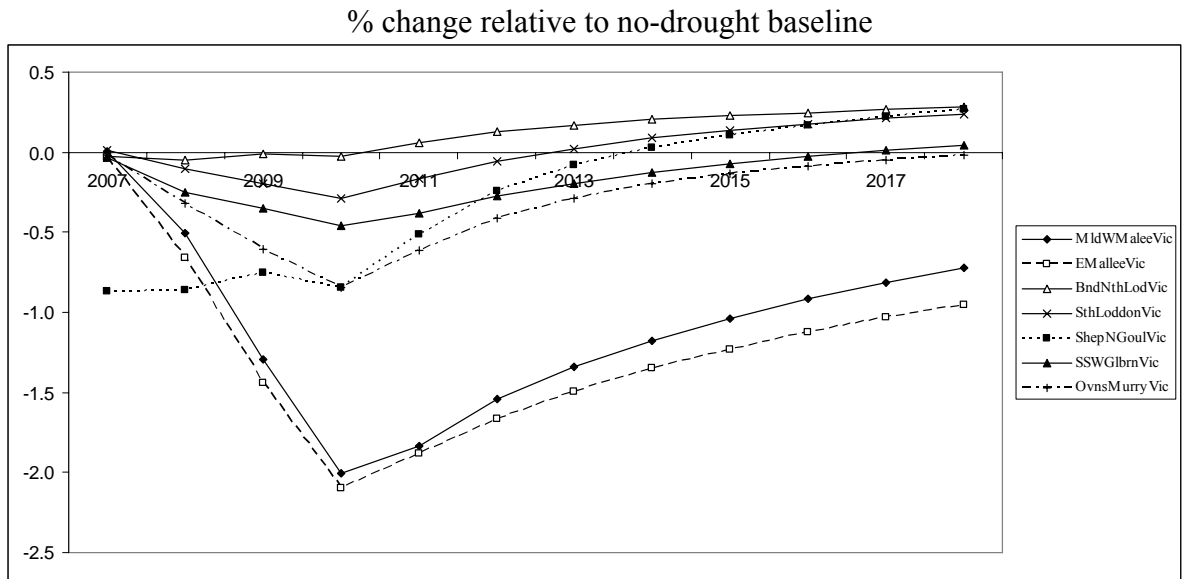
13

Figure 9: Impact of drought on capital stocks in remaining Sth MDB regions

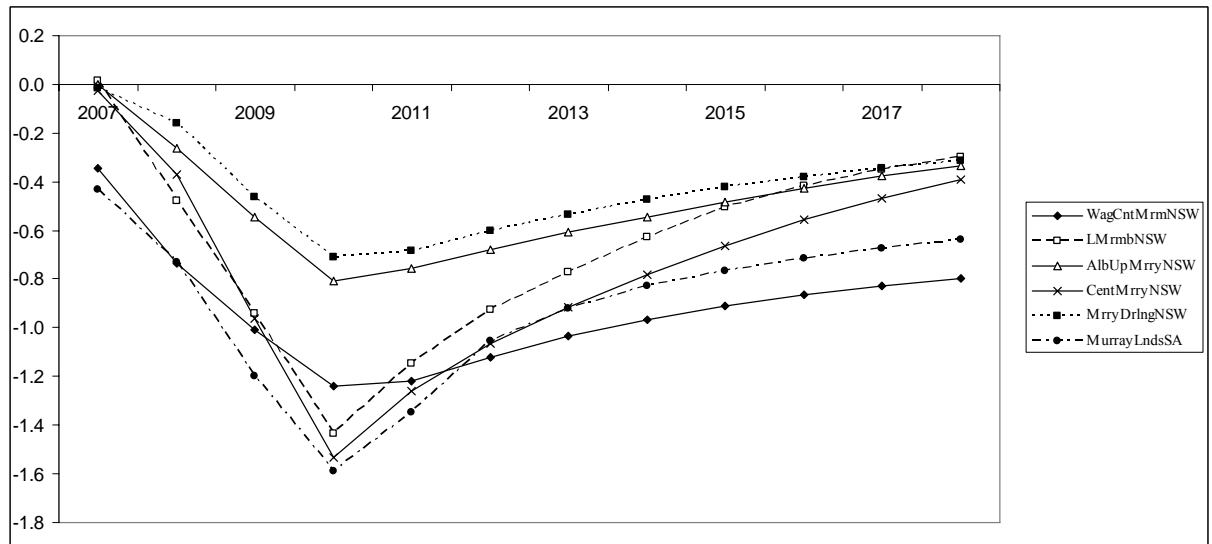% change relative to no-drought baseline

Figure 10: Impact of drought on aggregate consumption in Victorian regions
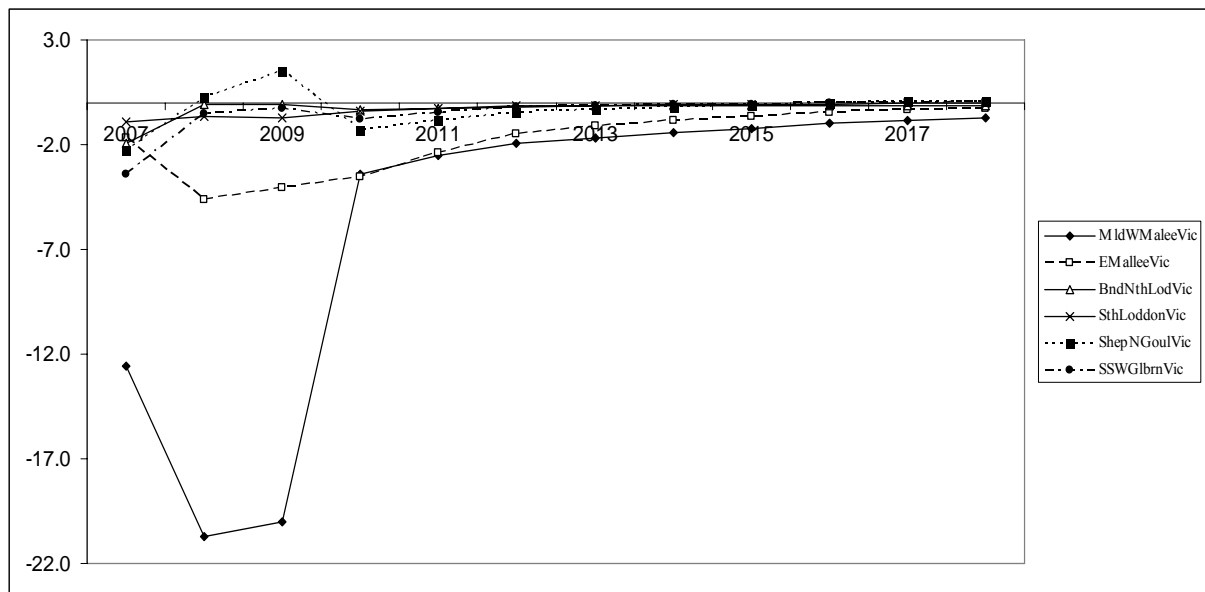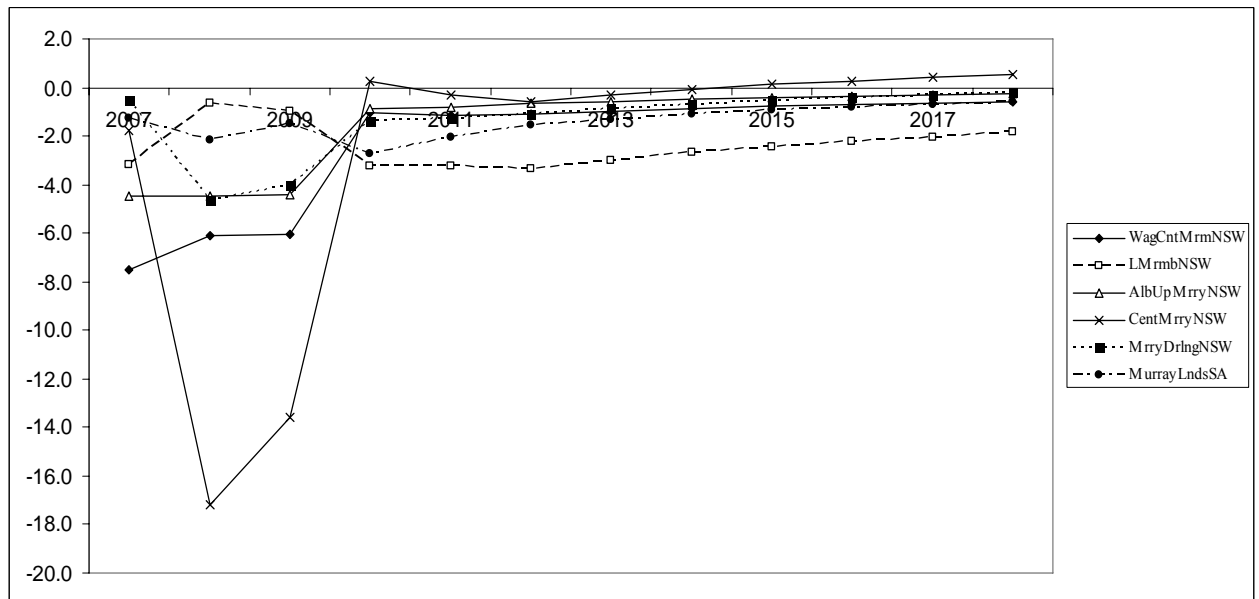% change relative to no-drought baseline

Figure 11: Impact of drought on aggregate consumption in remaining Sth MDB regions
% change relative to no-drought baseline

Figures 10 and 11 show the impact of drought on aggregate consumption in each region. Without the implementation of excess capacity in downstream sectors, many of the regions would have much smaller falls in aggregate consumption relative to forecast than otherwise.

The drought scenario as modelled does not consider changes in global market conditions which may have impacted adversely on some sectors. For example, during 2007 and 2008, some citrus orchards in the basin were taken out of production, a consequence of reduced water allocations combined with unfavourable commodity price movements. By 2009, grape producers were facing similar circumstances due to falling prices. Within the model, the broader fruit sector does relatively well because it is relatively frugal in water requirements

per unit of output. With adverse relative price movements for outputs included in the simulation, the modelled outcomes would change.

The Australian Water Market Report for 2007–08 shows an observed pattern of net downstream trade. Small amounts were transferred out from the upper Murray reaches in both NSW and Victoria, 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 lower Victorian Murray and most notably South Australia. In terms of how the modelling replicated this pattern, the main differences are that trade from the Murrumbidgee is overestimated, while trade to South Australia is underestimated. The modelling predicted that the upstream areas of the Murray, both NSW and Victoria, and the Goulburn region would be net buyers of water rather than sellers. In 2008–09, the Victorian Murray upstream of Barmah and Goulburn Valleys were net importers of water.

Available data on water trades show that TERM-H2O did a reasonable job of modelled the pattern of net trades. Differences in volumes traded may reflect estimates of reductions in water availability that differ from actual reductions. Other possible reasons why volumes of water traded might be less than modelled include physical and institutional barriers to water trading. Notably, the Victorian government's cap on trade, under which no more than a small percentage of permanent water could leave a water region, may have slowed or even halted permanent trading, to the detriment of allocative efficiency during the drought.

Explaining long-run impacts

Why do some regions not return to forecast real GDP by 2018 whereas others end up above forecast? Our first clue is in the contribution of net water trading to real GDP in MDB regions. Using a linear regression, we can explain most of the deviation in real GDP (gdp_r) in 2018 as the contribution of net water trading ($contNetWater_r$).

$$gdp_r = -0.545 + 1.270*contNetWater_r \qquad\qquad R^2=0.900$$

The net water trading variable has been normalized and divided by the standard deviation of the regional contributions. This means that the intercept term is the mean of the change in real GDP relative to forecast of the MDB regions in 2018. That this is below forecast even in the long run reflects the impact of prolonged drought on investment. Drought lowers the rate of return on farm capital relative to forecast, so that investment levels fall below forecast. Farm capital remains below forecast in the long run as investment after recovery is insufficient to allow accumulated farm capital to return to forecast levels. The capital to labour ratio (K/L) in each region moves with the factor price ratio (w/r). Since regional labour market adjustment in TERM-H2O occurs entirely through inter-regional migration without any contribution from inter-regional wage differentials relative to forecast, we expect no change in w (real wages) relative to forecast in 2018. That is, the MDB regions are too small for any labour change to influence national wages. In the long run, we expect the rate of return on capital (r) to return to forecast levels. Therefore, the factor price ratio (w/r) in the long run should return to control. In MDB regions, capital stocks have fallen due to drought, so employment must also fall so that as to maintain the relationship between the factor price ratio and the national capital to labour ratio. Hence, with both labour and capital below forecast, real GDP across the MDB remains below forecast in 2018.

Prolonged drought has caused disinvestment in both dry-land and irrigated sectors in the MDB. Primary factors used in dry-land production have fallen by 1.05 percent and non-water irrigation factors by 0.41 percent across the southern MDB. The marginal product of water has risen with the change in composition of irrigation farming.[4] The price of water in 2018 remains 14.4% above forecast despite full recovery from drought years beforehand. The pattern of water trading between regions changes relative to forecast with the change in the price of water. In regions that are net exporters (importers) of water, water trading contributes positively (negatively) to real GDP.

Table 3 shows the deviation from forecast in sectoral outputs and prices, and demand for water for 2007. Rice output falls by the largest percentage, with a near ten-fold increase in the water price driving water's cost share in production to high levels. As is explained in the derivation of the elasticity of demand for water (see Appendix B), rising water cost shares enlarge water's elasticity of demand. Irrigated cereals have a dry-land substitute, so that cereals also suffer a large fall in output. Conversely, the two irrigated livestock sectors, irrigated fruit and irrigated other agriculture all have increases in output. There are several reasons for this. First, with deterioration in dry-land productivity, there is a movement from dry-land to irrigated activities. With more non-water factors available per unit of water in irrigated activities, the marginal product of water increases. At the same time, there is substitution away from water as its price rises relative to other factors. This means, for example, that despite its water use falling by 26.5 percent relative to forecast, other irrigated livestock's output increases by 11.8 percent (Table 3) in the extreme conditions of 2007. As is shown in columns (5) and (6) of Table 3, rice has the highest own-price and output elasticity of demand for water.

Table 3: MDB irrigation in 2007
(relative to 2007 base)

	Output %	Price %	Water price %	Water used %	Elasticity wrt p_{water}	
					Water	Output
	(1)	(2)	(3)	(4)	(5)=(4)/(3)	(6)=(1)/(3)
CerealIrig	-44.8	46.9	859	-64.0	-0.075	-0.052
Rice	-77.3	68.9	859	-88.1	-0.103	-0.090
DairyCatIrig	1.7	31.4	859	-24.2	-0.028	0.002
OthLivstoIrg	11.8	48.0	859	-26.5	-0.031	0.014
Grapes	-13.0	15.6	859	-42.2	-0.049	-0.015
Vegetables	9.4	8.8	859	7.6	0.009	0.011
FruitIrig	3.6	14.2	859	-13.2	-0.015	0.004
OthAgriIrig	62.5	7.7	859	44.5	0.052	0.073

Table 4 shows the corresponding results for 2018. Since water availability is same in the drought simulation as in forecast, the elasticity of demand for water could be either positive or negative. Dairy cattle cuts water use more than any irrigation activity in response to higher than baseline water prices. This is a legacy of a rundown in dairy livestock capital in both irrigated and dry-land technologies.

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[4] If irrigation production consisted of a single sector, then a decline in non-water factors would lead to a decrease in the marginal product of water.

Table 4: MDB irrigation in 2018
(relative to 2018 base)

| | Output % | Price % | Water price % | Water used % | Elasticity wrt p_{water} | |
| | | | | | Water | Output |
	(1)	(2)	(3)	(4)	(5)=(4)/(3)	(6)=(1)/(3)
CerealIrig	0.1	-0.2	14.4	1.0	0.068	0.009
Rice	-0.3	-0.1	14.4	0.1	0.005	-0.017
DairyCatIrig	-2.2	-1.0	14.4	-3.0	-0.208	-0.152
OthLivstoIrg	3.1	-0.4	14.4	1.2	0.081	0.213
Grapes	-1.1	0.0	14.4	-0.6	-0.038	-0.075
Vegetables	0.0	-0.1	14.4	1.0	0.070	0.001
FruitIrig	-0.1	-0.5	14.4	0.5	0.036	-0.008
OthAgriIrig	0.0	0.0	14.4	0.6	0.043	0.003

Differences in long-run responses among irrigation activities, and their interaction with corresponding dry-land sectors where applicable, explain why there is a change in the water trading pattern relative to forecast many years after recovery from drought. As noted in the regression above, the pattern of water trading corresponds quite closely with the pattern of regional real GDP outcomes.

Since long-run regional outcomes depend on the pattern of water trading, and the latter depends on industry composition, we should be able to regress key long-run macro variables against database weights to explain results. We choose the percentage deviation in employment (l_r) from forecast, in 2018, regressed against irrigated agriculture's initial share of GDP ($Irig_r$) and dry-land agriculture's initial share of GDP (Dry_r).

$$l_r = —0.387 — 0.071*Irig_r— 0.191*Dry_r \qquad R^2=0.828$$

Our main finding quite simply is that the more intensive is a region in its reliance on agriculture, the more it suffers in the long run from drought as a consequence of several years of disinvestment in response to drought.

Terms of trade impacts over time

Three regions have curious outcomes in the deviation in aggregate consumption from forecast. Lower Murrumbidgee appears to do worse relative to forecast after recovery from drought than during the drought. In 2009, Shepparton-North Goulburn's aggregate consumption rises above forecast (Figure 10). And in Mildura-West Mallee,[5] aggregate consumption falls to more than 20 percent below forecast in 2008, considerably worse than the impact on real GDP. Figure 12 shows the CPI, GDP deflator (GI) and contribution of net water trading to the GDP deflator (contPw) for these three regions.

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[5] Central Murray suffered a similar drop in aggregate consumption in response to drought as Mildura-West Mallee. We limit the results in Figure 12 to three regions to simplify the presentation.

Figure 12: CPI, GDP deflator and contribution of water trading to GDP deflator
% change relative to no-drought baseline
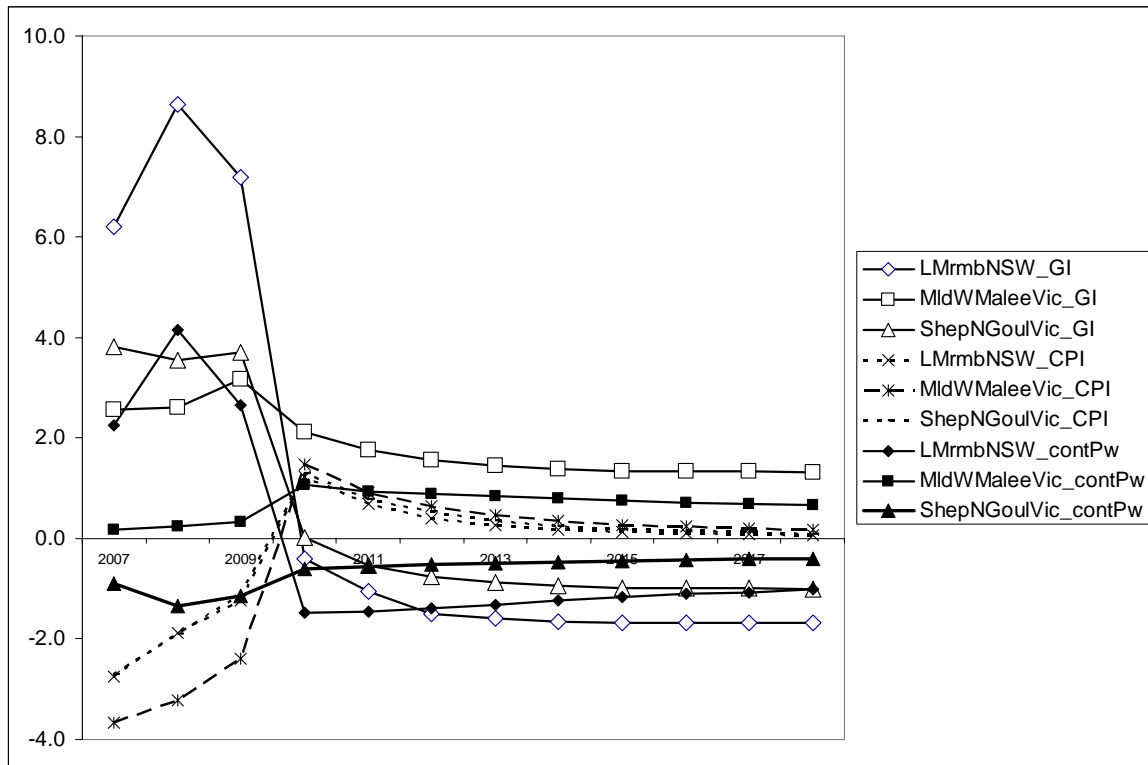
To explain why the contribution of net water trading to the terms of trade matters, we turn to the components of regional GDP in TERM-H2O:

$$GDP = C+I+G+(X-M)_{OS} +(X-M)_{inter-regional} +(X-M)_{water}$$

Instead of a single net trade expression as in the national identity, there are three, one for international trade (OS), one for inter-regional trade and one for net trade in water. Therefore, the GDP deflator will consist of the share-weighted sum of each of GDP component prices. The gap between the GDP deflator and CPI enlarges as a region's terms of trade improve. This is because GDP includes exports but not imports and CPI includes imports but not exports. The consumption function links changes in nominal consumption to changes in nominal disposable income[6]. Real consumption rises relative to real disposable income as the GDP deflator rises relative to CPI.

We assume that inter-regional water trades allow the price of water to be equalized across all regions. Since some regions are net exporters of water, the contribution of water trading to the GDP deflator is positive. For net importers, it is negative. Lower Murrumbidgee is a net exporter of water during the drought, but becomes a net importer following recovery from drought. This means that the contribution of water to the GDP deflator is positive during the drought years, but turns negative later. This explains much of why aggregate consumption in the region worsens rather than improves after the drought ends (Figure 11). In 2008, the GDP deflator is more than 8 percent above forecast. Half of this arises from the contribution of water exports. In subsequent recovery years, the GDP deflator turns negative. The consequent

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[6] Disposable income is equal to GNP, that is, excluding net earnings of foreign-owned capital in a region, minus interest payments on net foreign liabilities.

decline in the terms of trade combines with falling capital stocks to impact adversely on employment in later years. This in turn reduces aggregate consumption.

Shepparton-North Goulburn's real GDP relative to forecast in 2009 is -2.4 percent (Figure 3) and CPI -1.1 percent. At the same time, its GDP deflator is 3.7 percent above forecast, despite a negative contribution from the terms of trade (Figure 12). A modest fall in GDP combined with a sharp increase in the price of the region's production is sufficient to make aggregate consumption positive. This occurred even with a theory of excess capital applying to downstream sectors in the region. The implementation of excess capital in the region reduces the modelled terms of trade impact but not sufficiently to stop aggregate consumption from rising.

The GDP deflator in Mildura-West Mallee rises less above forecast during the prolonged drought than in the other two regions. But at the same time, its CPI falls more than in the other two regions, so it also has a terms of trade improvement. To explain why aggregate consumption falls by a larger percentage than real GDP, we recall the consumption function, which links nominal dollar changes in consumption to nominal dollar changes in disposable income. Falls in nominal GDP translate to larger percentage falls in nominal consumption, as the consumption to GDP ratio is less than one. Therefore, even with a terms of trade improvement during the worst of the drought, real consumption may fall by a larger percentage than real GDP. This effect is most obvious in years and regions with large percentage losses in real GDP.

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. By implementing excess capacity in downstream processing sectors, we have attempted to deal with implausibly large farm output price increases. We have moderated though not entirely eliminated exaggerated terms-of-trade effects. While we started the study conscious of terms of trade impacts, we had not considered the potentially large impacts that water trading may have on regional terms of trade. For regions with sufficient production flexibility, most notably Lower Murrumbidgee, it is possible to have substantial water trading terms of trade gains during drought.

There is a general pattern that regions do not recover to no-drought forecast levels, even with a return to average seasons. Disinvestment due to prolonged drought leads to a permanent reduction in farm output. The few farm regions that end up with aggregate consumption at or above forecast in the long run do so not because of a full recovery in regional GDP, but because terms of trade concerning water are favourable in the long run. Regions that do worse than average in this study in the long run do so because they suffer adverse terms of trade effects arising from water trading. Water becomes more valuable even with a return to normal seasons.

Irrigators may have felt in the past that they were insulated from drought, if not from the other fluctuations that have impacted on farm profitability. Repeated shortfalls in water allocations presented a new crisis for irrigators in the first decade of the new millennium. Various options to deal with the new crisis, including water trading, have been insufficient in the face of the severity of drought in the past few years. TERM-H2O includes detailed treatment of both irrigation and dry-land sectors, with mobility of farm factors between the two groups. This makes TERM-H2O a unique tool for analysing a number of farm issues including drought. It

also means that TERM-H2O could model different types of drought. For example, it could model a year of severe rainfall deficiencies combined with near normal irrigation water allocations. Models that do not include dry-land sectors would not model sharp increases in water prices in such circumstances. TERM-H2O will because such a drought would induce a movement of farm factors from dry-land to irrigated sectors, thereby raising the marginal product of water.

An important contribution that the CGE approach makes to drought analysis is to provide an awareness of the shrinking contribution of farm and downstream sectors to regional GDP over time. Our modelling shows that periods of prolonged drought may exacerbate such decline. To put this in context, agriculture's share of GDP for all of Australia was around 13 percent in the early 1960s (Maddock and McLean, 1987). Now, the contribution of farming in the SMDB basin to GDP is less than 13 percent (Table 2). This indicates that policy efforts in the basin must increasingly concentrate on service sectors. Regional communities are aware of the importance of keeping schools and hospitals open both to service their communities and to provide employment. Moreover, to the extent that regional communities are aging, the need for health and aged care services will grow. It may be tempting during a regional economic crisis brought on by drought to consider only the impact on farming and associated sectors such as farm implement dealers. Communities may suffer much more if publicly funded services are allowed to deteriorate in such a crisis.

References

ABS (2009a), Experimental Estimates of the Gross Value of Irrigated Agricultural Production, 2000–01 to 2006–07, Catalogue 4610.0.55.008 .

ABS (2009b), *Regional Population Growth, Australia*. Catalogue 3218.0 .

Dixon, P, Parmenter, B., Sutton, J. and Vincent, D. (1982) ORANI: A Multisectoral Model of the Australian Economy, Amsterdam, North-Holland.

Dixon, P., Rimmer, M. and Wittwer, G. (2010) "Modelling the Australian government's buyback scheme with a dynamic multi-regional CGE model", Monash University, Centre of Policy Studies Working Paper G-186.

Rimmer, M., Dixon, P., Johnson, M. and Rasmussen, C. (2009), "The effects of a credit crisis: simulations with the USAGE model", Paper presented to the 12th annual Global Trade Analysis Project conference, Santiago, Chile, June 10-12.

Horridge, M, Madden, J. and 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(3):285-308, May.

Harrison, J., Horridge, M., Pearson, K. and Wittwer, G. (2004), "A practical method for explicitly modeling quotas and other complementarities", *Computational Economics* 23(4): 325-341, June.

Maddock, R. and McLean, I., (1987), "The Australian economy in the very long run", Maddock, R., McLean, I., (Eds.), *The Australian Economy in the Long Run*. Cambridge University Press, Cambridge.

Wittwer, G. (2003), "An outline of TERM and modifications to include water usage in the Murray-Darling Basin". Downloadable from www.monash.edu.au/policy/archivep.htm TPGW0050.

Wittwer, G., McKirdy, S. and Wilson, R. (2005), "The regional economic impacts of a plant disease incursion using a general equilibrium approach", *Australian Journal of Agricultural and Resource Economics* 49(1): 75-89, March.

Wittwer, G. (2009), "The economic impacts of a new dam in South-east Queensland", *Australian Economic Papers*, 42(1):12-23, March.

Young, M., Proctor, W., Qureshi, E. and Wittwer, G. (2006), *Without Water: The economics of supplying water to 5 million more Australians,* CSIRO Land and Water and Centre for Policy Studies, May http://www.myoung.net.au/water/publications/WithoutWater.pdf

Appendix A
Figure A1: Production function for farm sectors
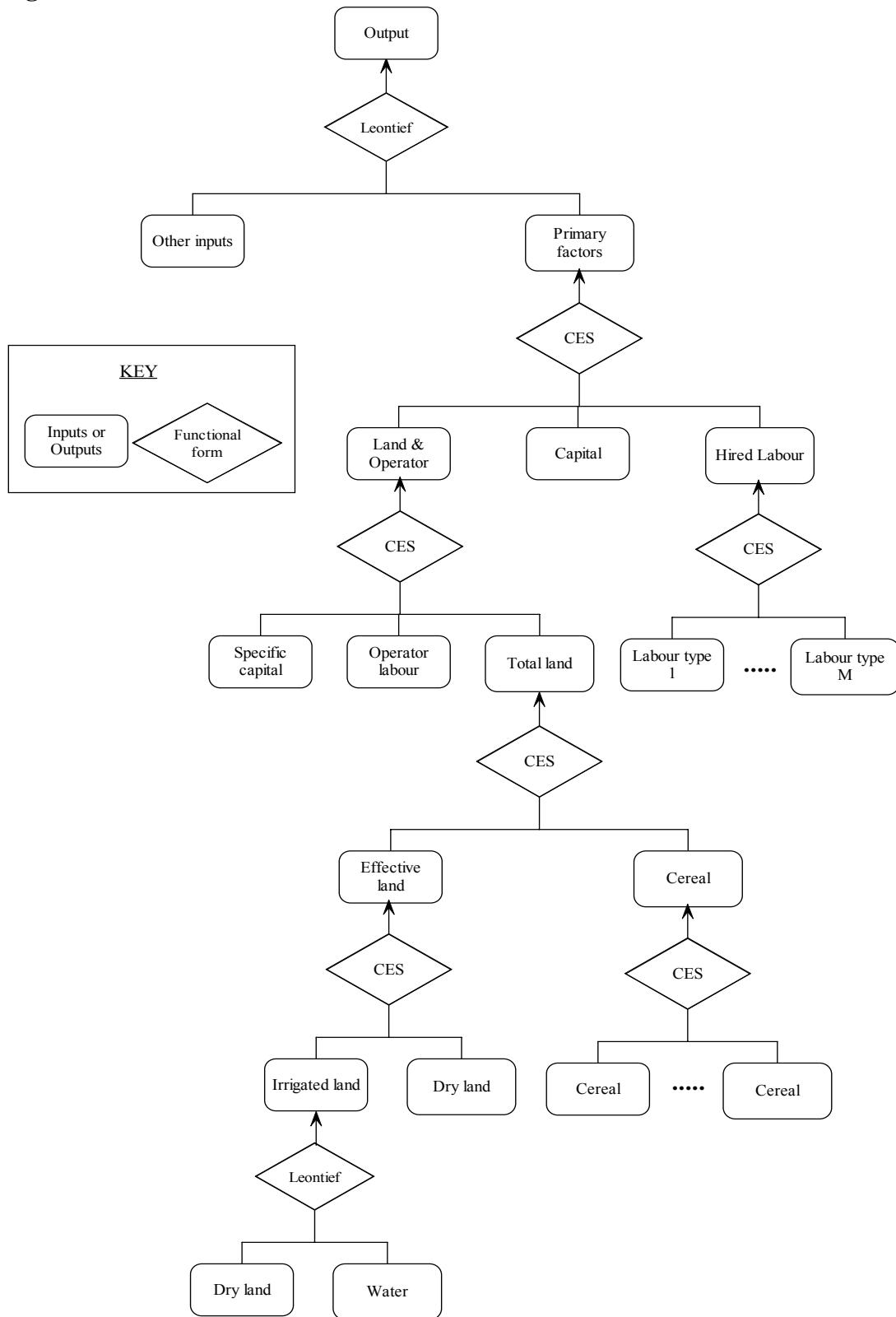
Appendix B: sectoral responses to changes in the water price

In TERM-H2O, farm factors appear in a series of CES nests (Figure xx). Water application per hectare of irrigable land is constant at a given water-using technology. Irrigable land inclusive of water and dry land are substitutable in (A1), forming a CES land nest that in turn is substitutable with owner-operator inputs for industry (A2).

$$x_{wdi} = x_{li} - \sigma_{wd} (p_{wdi} - p_{li}) \qquad \text{irrigable-dry land substitution} \qquad (A1)$$

$$x_{li} = x_{oi} - \sigma_o (p_{li} - p_{oi}) \qquad \text{land-owner substitution} \qquad (A2)$$

The percentage change in land type *wd* in industry *i* is x_{wdi}, with the corresponding price term being p_{wdi} and the CES parameter σ_{wd}. The composite land demanded is x_{li} and its price p_{li}. The land-owner composite is substitutable with other primary factors (A3). The CES parameter σ_{oi} concerns land and owner operator substitution. The land-owner composite demanded is x_{oi} and p_{oi} is its price.

$$x_{oi} = x_{fi} - \sigma_f (p_{oi} - p_{fi}) \qquad \text{land-owner and other factor substitution (A3)}$$

We obtain an expression for the demand for water (x_{wi}) in a single equation by substituting (A3) and (A2) into (A1), and using the constraint that water usage is proportional to land in irrigation activities (where $x_{wi} = x_{wdi}$ for *wd*= "irrigated land"):

$$x_{wi} = x_{fi} - \sigma_f (p_{oi} - p_{fi}) - \sigma_o (p_{li} - p_{oi}) - \sigma_{wd} (p_{wdi} - p_{li}) \qquad (A4)$$

Each of the price terms can be split in water and non-water parts, where p* is the non-water composite price in each equation and the S terms are cost shares for water (S_{wi}), the land composite ($S_{land,i}$) and land-owner composite ($S_{land-owner,i}$) respectively:

$$p_{wdi} = S_{wi} p_{wi} + (1 - S_{wi}) p_{wdi} \qquad (A5)$$

$$p_{li} = S_{wi} \cdot p_{wi} \cdot S_{land,i} + (1 - S_{wi} \cdot S_{land,i\, i}) p^*_{li} \qquad (A6)$$

$$p_{oi} = S_{wi} \cdot p_{wi} \cdot S_{land,i} \cdot S_{land-owner,i} + (1 - S_{wi} \cdot S_{land,i\, i} \cdot S_{land-owner,i}) p^*_{fi} \qquad (A7)$$

Substituting in the cost share terms and dividing by p_{wi}, we obtain an expression for the elasticity of demand for water:

$$
\begin{aligned}
x_{wi}/p_{wi} = x_{fi}/p_{wi} \\
- \sigma_f ([S_{li} S_{wi} S_{land-owner\, i}] + ((1 - [\ldots]) p^*_{fi} - p_{fi})/p_{wi}) \\
- \sigma_o ([[S_{wi} S_{land,i}]] + ((1 - [[\ldots]]) p^*_{oi} - p_{oi})/p_{wi}) \\
- \sigma_{wd} (S_{wi} + ((1 - S_{wi}) p_{wdi} - p_{li})/p_{wi})
\end{aligned}
\qquad (A8)
$$

The elasticity of demand for water for an individual activity subject to an overall water constraint could be positive or negative. The elasticity of output with respect to the water price (x_{fi}/p_{wi}) is also of either sign, given the overall water constraint (i.e., the change in water usage in MDB in 2018 relative to forecast is zero, whereas it is large and negative in 2007). The x_{fi}/p_{wi} component usually dominates the overall expression. When water's cost share of total production is large, the remainder of the expression may become more important. However, if water's cost share is large and water trading is permitted, it is probable there will be substantial movement of water towards other activities (i.e., substantial specific substitution) and a large x_{wi}/p_{wi} component as water scarcity worsens.