

Eleventh Floor, Menzies Building
Monash University, Wellington Road
CLAYTON Vic 3800 AUSTRALIA

Telephone:
(03) 9905 2398, (03) 9905 5112

Fax:
(03) 9905 2426

e-mail:
Internet home page:

from overseas:
61 3 9905 2398 or
61 3 9905 5112

61 3 9905 2426

impact@buseco.monash.edu.au

<http://www.monash.edu.au/policy/>

Modelling the Australian Government's Buyback Scheme with a Dynamic Multi-Regional CGE Model

by

PETER B. DIXON
*Centre of Policy Studies
Monash University*

MAUREEN T. RIMMER
*Centre of Policy Studies
Monash University*

And

GLYN WITTWER
*Centre of Policy Studies
Monash University*

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Modelling the Australian government's buyback scheme with a dynamic multi-regional CGE model

Peter B. Dixon, Maureen T. Rimmer and Glyn Wittwer

April 2009

Abstract

TERM-H2O is a multi-regional model of the Australian economy adapted to include regional water accounts. Factors of production are mobile between sectors in farm industries. TERM-H2O is dynamic and also includes complementarity conditions that impose constraints on the volume of irrigation water traded between regions.

The application detailed here is to the Commonwealth government's water buyback scheme against a background of temporary drought. The buyback scheme provides a windfall gain for holders of water rights by raising the price of irrigation water. The scheme may provide a net benefit to irrigation regions while increasing environmental flows.

JEL classification: C68, Q25, R13, R15.

Keywords: regional modelling, CGE modelling, water.

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1. Background

Irrigation in the southern Murray-Darling basin (SMDB) is suffering an ongoing crisis. Over a decade of below average rainfall in south east Australia combined with irrigation entitlements based on years of higher rainfall have resulted in shortfalls in water allocations to irrigators. To put into context the severity of the current crisis, Goulburn-Murray Water (2009) aims to deliver full entitlements to irrigators in 97 years out of 100. In four of the past six years, there have been allocations in the region below 100 percent.

There has been growing community awareness of the state of the Murray-Darling basin, particularly concerning the lakes at the mouth and the World Heritage listed Coorong. Successive Commonwealth governments in principle have agreed to a buyback scheme that will release water for environmental flows. The environmental benefits of the scheme have been confounded by the extreme water scarcity since 2006. In particular, spring rainfalls vital in catchment regions in south east Australia were far below average for three successive years from 2006 to 2008. So dire is the current circumstance that it may not be possible to maintain all wetlands and lakes in the SMDB, even with a buyback scheme that removes a substantial proportion of water allocations from irrigation (Young and McColl, 2009).

Severe difficulties have arisen for irrigators of perennial crops or livestock herds which require a minimum amount of water. In the wake of water crisis, substantial areas of orchards, notably citrus, have been removed as a result of an inability to withstand water shortfalls for even a single year, combined with rising import competition. Dairy cattle production has proven slightly more resilient, as operators have purchased fodder and grain as partial substitutes for green pasture. Although the grape and wine sectors have endured a series of crises since the turn of the millennium, first in the form of oversupply, then a rising Australian dollar (due to the resources boom from 2004 to 2008) and worsening water scarcity, vineyards appear to be somewhat more able to tolerate temporary shortfalls of water than citrus plantations. Overall, however, a severe water crisis remains that is imposing stresses on all irrigators in the SMDB.

This study uses a dynamic multi-regional computable general equilibrium (CGE) model that includes water accounts to model the Commonwealth's buyback scheme. The model includes 35 industries, including 17 farm and 10 irrigation sectors, producing 28 commodities in 22 regions in a bottom-up framework. Substantial theoretical modifications have been made to standard CGE models such as ORANI (Dixon *et al.*, 1982) and TERM (Horridge *et al.*, 2005) to represent irrigation sectors in a multi-regional CGE framework. Sections 2 to 5 detail the theoretical and database modifications to the model. In summary, these modifications ensure that there are significant supply responses as water availability changes, with a movement away from water-intensive crops as water scarcity worsens.

2. Theoretical modifications to farm industries in TERM-H2O: input-output structure

An effective way to gain an introductory understanding of a CGE model such as TERM-H2O is to look at key aspects of the input-output structure. The columns of an input-output table contain an industry's cost structure and the rows contain a commodity's sales structure. The input-output table also serves another role. It depicts the economy's initial

situation, that is, it provides the initial solution of the model. In modelling undertaken in this paper, we start with a 2005-06 database, the most recent year in which irrigation water in south east Australia was relatively abundant.

Figure 1 is a representation of the TERM-H2O's input-output structure for the farm sector in a region. The columns refer to farm industries. In TERM-H2O, industries are defined by region, irrigation status and main product. Examples of farm industries are: Lower Murrumbidgee/irrigated/cereal; Lower Murrumbidgee/dry/cotton; Rest of NSW/dry/other livestock. As well as their main product, some farm industries, those producing livestock, also produce pasture. While each farm industry produces just one main product, all agricultural products are produced by several industries. For example, Rest of NSW/irrigated/cotton, Queensland/irrigated/cotton, and Rest of NSW /dry/cotton all produce cotton.

We adopt the concept of single-main-product farm industries because it is in line with available data from the Australian Bureau of Statistics (ABS). These data show outputs by commodity and region. Data exist on the area of irrigation by broad activity, which serve as a starting point for splitting irrigated from dry land activity. At first glance it may seem that our single-product approach is in tension with the Australian reality of multi-commodity farm enterprises (e.g. wheat/sheep farms). However, in the theory described in this paper, a given farm enterprise can be spread across several farm industries. Our model allows for price-induced movements of productive resources between farm industries. We can think of such movements as occurring at the farm level with the farm manager re-allocating labour, land and other resources between the production of different commodities.

The rows of figure 1 refer to values of inputs and outputs. The first $N \times (R+1)$ rows (labelled Intermediate) are flows of N intermediate inputs to farm industries in region d from R regions of Australia and from abroad (imports). The next $3R$ rows refer to inputs that receive special treatment in TERM-H2O: pasture, cereal and other agriculture differentiated by region of supply. As we will see in section A2, these inputs are combined to form feed for livestock. Another special input is irrigation water. This is water obtained from an irrigation authority by allocation or trading, or from rain falling on land being used by irrigated industries. The remaining $M+4$ input rows are a disaggregation of value added into returns to: fixed capital; M types of hired labour; operator labour (the farmer); dry land; and unwatered irrigable land (rent excluding the value of irrigation water). The sum over all inputs for an industry gives the value of the industry's output. This can also be obtained in figure 1 by adding the last two rows containing the value of the industry's main product and the value of the industry's pasture production.

Figure 1: Farm industries in region d in the input-output data for TERM-H2O*

	Irrigated industries					Dry industries				
	Livestock (2)		Crops (8)			Livestock (2)		Crops (5)		
Inputs										
Intermediate (26x19)	Y	Y	Y	...	Y	Y	Y	Y	...	Y
Pasture (18)	√	√	-	...	-	√	√	-	...	-
Cereal (18)	-	-	-	...	-	√	√	-	...	-
Other agriculture (18)	-	-	-	...	-	√	√	-	...	-
Irrigation water	√	√	√	...	√	-	-	-	...	-
Capital	Y	Y	Y	...	Y	Y	Y	Y	...	Y
Hired labour (9)	Y	Y	Y	...	Y	Y	Y	Y	...	Y
Operator labour	Y	Y	Y	...	Y	Y	Y	Y	...	Y
Dry Land	-	-	-	...	-	√	√	√	...	√
Unwatered irrigable land	√	√	√	...	√	√	√	√	...	√
	Total	Total	Total	...	Total	Total	Total	Total	...	Total
Outputs										
Main product	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Pasture	√	√	-	...	-	√	√	-	...	-

* Y indicates a potentially substantial entry, e.g. all industries use intermediate inputs

Ticks indicate flows of particular interest for this paper. A large √ indicates a potentially large value for a small √ indicates a small value

- indicates a zero or negligible value

The figure indicates that:

- all farm industries use hired labour and operator labour;
- only irrigated industries use irrigation water;
- only dry industries use dry land;
- all farm industries use unwatered irrigable land (that is land that can receive water from river- and dam-based irrigation systems controlled by water authorities) but only small amounts are used in dry industries;
- dry livestock industries use inputs of pasture (includes hay), cereal and other agriculture which they combine to form feed for livestock;
- crops industries do not use inputs of pasture, cereal and other agriculture;
- irrigated livestock industries do not use inputs of cereal and other agriculture but they do use inputs of pasture, predominantly home grown; and
- only livestock industries produce pasture.

By specifying pasture as both an input and output for livestock industries, TERM-H2O allows for the possibility of trade in hay. This is important for drought simulations.

3. Production and input-demand functions for farm industries in TERM-H2O

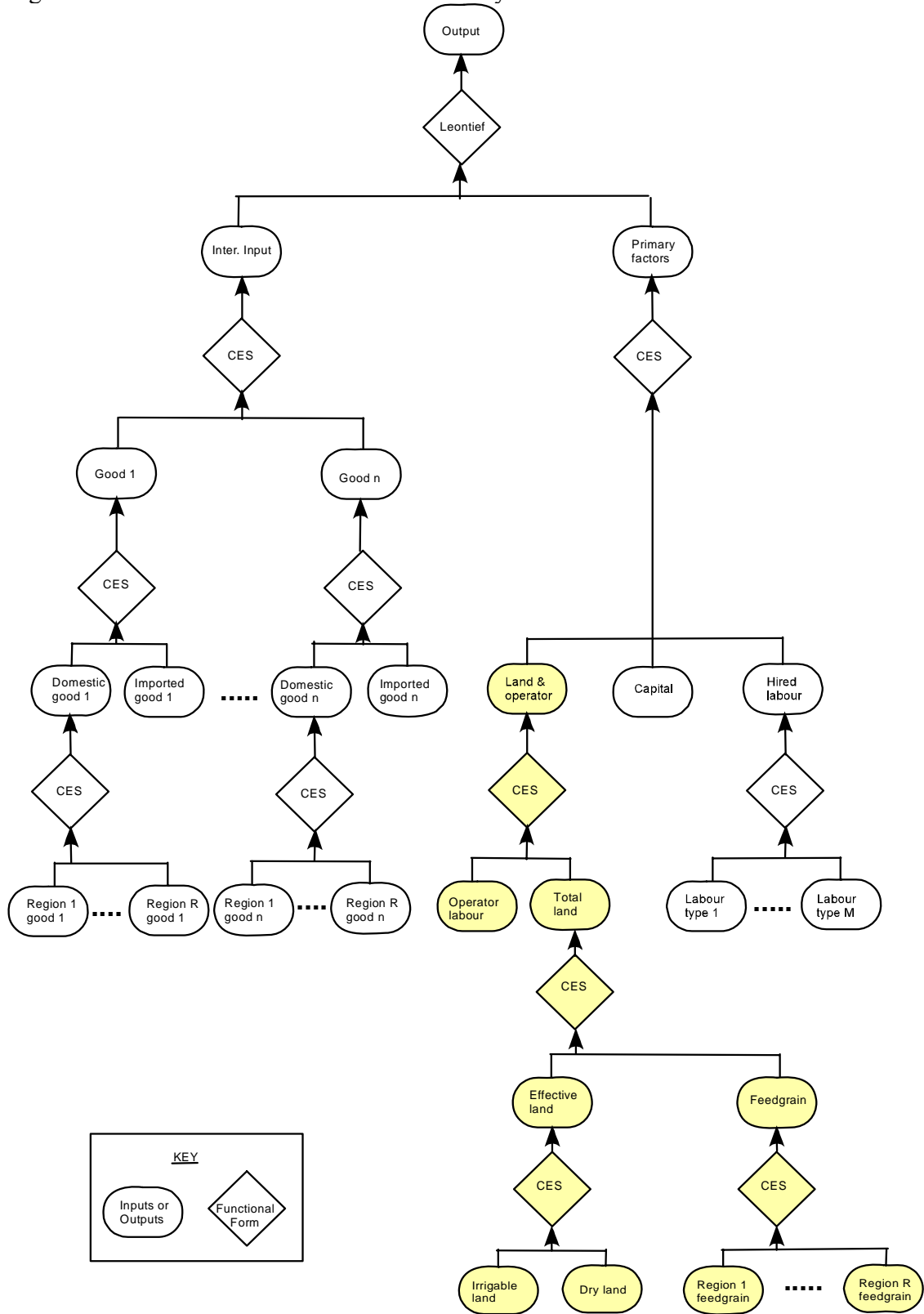
In this section we describe the production functions adopted in TERM-H2O. Then in section 3.4 we set out implied input-demand functions and show how these are calibrated using data of the type represented in figure 1.

We consider farm industry (q,d) where q refers to the industry's irrigation status and crop (e.g. irrigated/rice) and d refers to the industry's region (e.g. Lower Murrumbidgee). The structure of the (q,d) 's production function is illustrated in figure 2.

As in other versions of TERM, we assume that output is a Leontief function of intermediate input and primary factor. Intermediate input is a CES combination of inputs of goods 1 to N . Each of the goods 1 to N is a CES combination of the imported and domestic varieties. The domestic variety of good i is a CES combination of good i produced in each of the R regions. Primary factor is a CES combination of three inputs: land & operator; physical capital; and hired labour. Hired labour is a CES combination of labour of M different occupations or skill categories.

The only part of the structure in figure 2 that is a departure from earlier versions of TERM, and the only part that receives any further attention in this paper, is the treatment of land & operator (the shaded part of figure 2). In earlier versions, there were no underlying inputs generating land & operator. In TERM-H2O, land & operator is a CES nest of inputs of operator labour (the farmer) and of total land. There are then several nests below total land.

Figure 2: Production function for a farm industry



The first of these nests makes total land a CES combination of effective land and feed grain (possibly including purchased hay). This nest is relevant only for dry-land livestock industries: for other industries the use of feed grain in our database is negligible, ensuring that total land is simply effective land. For dry-land livestock industries we recognize that feed grain is a substitute for land: a given amount of livestock can be maintained on less land if we use more feed grain. We assume that all feed grain is domestically produced. As with other domestically produced intermediate inputs, we model the input of feed grain as a CES combination of inputs from the R regions.

In the nest below effective land we make irrigable land a substitute for dry land. This is relevant only for dry-land industries: for irrigation industries the use of dry land in our database is negligible, ensuring that effective land is simply the input of irrigable land. On the other hand, we recognise that dry-land industries can use both dry land and irrigable land. As will be explained shortly, TERM-H2O implies that dry-land industries will use significant amounts of irrigable land when there are shortages of irrigation water. The bottom nest concerns the input of irrigation water. We model this in a Leontief nest with unwatered irrigable land. Thus we assume that irrigable land used by industry (q,d) is always fully watered. However, the meaning of “fully watered” varies from industry to industry. For dry-land industries, we set up the initial input-output data so that there is negligible use of irrigation water in the Leontief nest with unwatered irrigable land. This ensures that dry-land industries use unwatered irrigable land as though it were dry land.

In simulations in which shortages of irrigation water worsen, TERM-H2O generates increases in the prices of irrigation water. This causes reductions in the rental values of unwatered irrigable land. Because dry-land industries do not use irrigation water with their inputs of irrigable land, there is a reduction in the cost to these industries of using irrigable land. This leads to an increase in the demand for irrigable land by dry-land industries via CES substitution of irrigable and dry land.

3.1 Land & operator specification for farm industries in TERM-H2O

In this section, we discuss the details of the land & operator specification in figure 2 together with the implied input-demand equations for irrigation water, unwatered irrigable land, irrigable land, dry land, operator labour and feed grain.

Composition of effective-land input

In deciding its inputs of irrigable land (LNI) and dry land (LND) we assume that farm industry (q,d)

$$\begin{array}{ll} \text{chooses} & \text{XLN}(q, d, k), k \in \{\text{LNI}, \text{LND}\} \\ \text{to minimize} & \sum_k \text{PLN}(q, d, k) * \text{XLN}(q, d, k) \end{array} \quad (1)$$

$$\text{subject to} \quad \text{XELFG}(q, d, \text{EL}) = \text{CES}_k(\text{XLN}(q, d, k)) \quad (2)$$

where

XLN(q,d,k) refers to inputs to industry (q,d) of input k (irrigable land or dry land);

PLN(q,d,k) is the cost to industry (q,d) of using a unit of land of type k;¹ and

XELFG(q,d, EL) is a measure of (q,d)'s requirements for effective land.

We define the cost of using a unit of effective land to industry (q,d) as:

$$PELFG(q, d, EL) = \frac{\sum_k PLN(q, d, k) * XLN(q, d, k)}{XELFG(q, d, EL)} \quad (3)$$

Models such as TERM-H2O are computed with equations that are linear in percentage changes. The percentage-change equations arising from (1) to (3) that are included in TERM-H2O are:

$$xln(q, d, k) = xelfg(q, d, EL) - \sigma_{ln}(q, d)[pln(q, d, k) - pelfg(q, d, EL)], \quad k \in \{LNI, LND\} \quad (4)$$

and

$$pelfg(q, d, EL) = \sum_k SLN(q, d, k) * pln(q, d, k) \quad (5)$$

where

xln(q,d,k), x(q,d,land), pln(q,d,k) and p(q,d,land) are percentage changes in the variables defined by the corresponding uppercase symbols;

$\sigma_{ln}(q,d)$ is (q,d)'s the elasticity of substitution between irrigable land and dry land in the generation of the overall input of effective land; and

SLN(q,d,k) is the share of k (irrigable land or dry land) in (q,d)'s cost of using effective land, that is:

$$SLN(q, d, k) = \frac{PLN(q, d, k) * XLN(q, d, k)}{\sum_j PLN(q, d, j) * XLN(q, d, j)}, \quad k \in \{LNI, LND\} \quad (6)$$

3.2 Composition of total-land input

In deciding its inputs of effective land (EL) and feed grain (FG) we assume that farm industry (q,d)

$$\begin{aligned} &\text{chooses} && XELFG(q, d, k), \quad k \in \{EL, FG\} \\ &\text{to minimize} && \sum_k PELFG(q, d, k) * XELFG(q, d, k) \end{aligned} \quad (7)$$

subject to

$$XTLOP(q, d, \text{total land}) = CES_k (XELFG(q, d, k) / AELFG(q, d, k)) \quad (8)$$

where

XELFG(q,d,k) refers to inputs to industry (q,d) of k (effective land or feed grain);

¹ As we will see, in the case of irrigable land used by irrigated industries, this cost includes not only rent but also the cost of irrigation water.

PELFG(q,d,k) is the cost to industry (q,d) of using a unit of input k (effective land or feed grain)²;

XTLOP(q,d, total land) is (q,d)'s total requirements of land (a composite of effective land and feed grain or a measure of land input with associated food for maintaining livestock); and

AELFG(q,d,k) are variables that can be used to introduce productivity change. For example, if AELFG(q,d, EL) increases by 50 per cent, then for any given input of feed grain, industry (q,d) needs 50 per cent more effective land to achieve any given level of total land requirements. Equivalently, if AELFG(q,d, EL) increases and effective land input is held constant, then industry (q,d) will need to increase its input of feed grain to achieve a given level of total land input. As we will see, AELFG(q,d, EL) can be used in simulations of the effects of changes in the weather.

The percentage-change equations arising from (7) and (8) that are included in TERM-H2O are:

$$\begin{aligned} xelfg(q, d, k) - aelfg(q, d, k) &= xtlop(q, d) \\ &- \sigma_{tlop}(q, d) \left[pelfg(q, d, k) - \sum_j SELFG(q, d, j) * pelfg(q, d, j) \right] \\ &- \sigma_{tlop}(q, d) \left[aelfg(q, d, k) - \sum_j SELFG(q, d, j) * aelfg(q, d, j) \right] \quad , \quad k \in \{EL, FG\} \end{aligned} \quad (9)$$

where

$xelfg(q,d,k)$, $pelfg(q,d,k)$, $aelfg(q,d,k)$ are percentage changes in the variables defined by the corresponding uppercase symbols;

$\sigma_{tlop}(q,d)$ is (q,d)'s the elasticity of substitution between effective land and feed grain in the generation of input of total land; and

SELFG(q,d,j) is the share of j (effective land and feed grain) in (q,d)'s cost of total land, that is:

$$SELFG(q, d, j) = \frac{PELFG(q, d, j) * XELFG(q, d, j)}{\sum_k PELFG(q, d, k) * XELFG(q, d, k)} \quad , \quad j \in \{EL, FG\} \quad . \quad (10)$$

3.3 Composition of land-&-operator input

In deciding its inputs of total land (TL) and operator labour (OP), we assume that farm industry (q,d)

$$\begin{aligned} \text{chooses} \quad & XTLOP(q, d, k), \quad k \in \{TL, OP\} \\ \text{to minimize} \quad & \sum_k PTLOP(q, d, k) * XTLOP(q, d, k) \end{aligned} \quad (11)$$

$$\text{subject to} \quad XLOKH(q, d, OP) = CES_k (XTLOP(q, d, k)) \quad (12)$$

where

² PELFG(q,d, EL) is defined by (3). PELFG(q,d, FG) can be defined in a standard way in terms of prices of feed grain from different regions via the CES specification in the bottom right hand corner of Figure 1.

XTLOP(q,d,k) refers to inputs to industry (q,d) of k (total land or operator labour);

PTLOP(q,d,k) is the cost to industry (q,d) of using a unit of input k³;

XLOKH(q,d,LO) is a measure of (q,d)'s total requirements of land & operator (LO).

The percentage-change equations arising from (7) and (8) that are included in TERM-H2O are:

$$xtlop(q,d,k) = xlokh(q,d,LO) - \sigma(q,d) \left[ptlop(q,d,k) - \sum_j S(q,d,j) * ptlop(q,d,j) \right],$$

$$k \in \{TL, OP\} \quad (13)$$

where

xtlop(q,d,k), ptlop(q,d,k), xlokh(q,d,LO) are percentage changes in the variables defined by the corresponding uppercase symbols;

$\sigma(q,d)$ is (q,d)'s the elasticity of substitution between total land and operator labour in the generation of the overall input of land & operator; and

$S(q,d,j)$ is the share of j (total land or operator labour) in (q,d)'s cost of land & operator, that is:

$$S(q,d,j) = \frac{PTLOP(q,d,j) * XTLOP(q,d,j)}{\sum_k PTLOP(q,d,k) * XTLOP(q,d,k)}, j \in \{TL, OP\} . \quad (14)$$

3.4 Calibrating input-demand equations in TERM-H2O

To implement equations (4), (5), (9) and (13) in TERM-H2O, we need to specify values for substitution parameters and initial values for share coefficients.

The initial values for the share coefficients are computed from the input-output database represented by figure 1. SLN(q,d,k) used in (5) is computed from the dry-land and irrigable-land rows of figure 1. SELFG(q,d,j) used in (9) is computed from the feed grain row and the sum of the two land rows. $S(q,d,j)$ used in (13) is computed from the operator-labour row and the sum of the feed grain row with the two land rows.

For $\sigma_{ln}(q,d)$, the elasticity of substitution between irrigable land and dry land appearing in (4), we adopt a high value, 10.0. As explained earlier, this elasticity plays a role only for dry-land industries. We adopt a high substitution value because whenever irrigable land is used by a dry industry this land is similar to dry land because it is not irrigated.

For $\sigma_{ilop}(q,d)$, the elasticity of substitution between effective land and feed grain appearing in (9), we also adopted a high value, 5.0. This elasticity is relevant only for dry-land livestock industries. Our reason for adopting a high value is that a given number

³ Movements in PTLOP(q,d,OP) are determined by movements in the demand for and supply of owner operators (see subsection 2.3). Percentage movements in PTLOP(q,d,TL) are determined according to:

$$ptlop(q,d,TL) = \sum_k SELFG(q,d,k) * (pelfg(q,d,k) + aelfg(q,d,k)) .$$

by a cost-share weighted average of the percentage movements of effective land and feed grain plus a cost-share weighted average of the aelfg(q,d,k), $k \in \{EL, FG\}$.

of livestock can be maintained on a small allocation of dry land with a large allocation of feed grain or on a large allocation of land with a small allocation of feed grain.

For $\sigma(q,d)$, the elasticity of substitution between total land and operator labour appearing in (13), we adopted a relatively low value, 0.5. For irrigation industries, this is approximately equivalent to assuming a fixed amount of operator labour per hectare of land used. This is because for an irrigation industry, input of effective land and total land move closely in line with hectares of irrigable land.

What does the adoption of a low value for $\sigma(q,d)$ in (13) mean for dry industries? For dry industries, the connection between effective land, $XELFG(q,d,EL)$, and hectares of land input is not as tight as for irrigation industries. Nevertheless, with high substitution between irrigable and dry land [high values for $\sigma_{in}(q,d)$] we can think of $XELFG(q,d,EL)$ as being the number of hectares of land used.⁴ For dry non-livestock industries, total land is approximately $XELFG(q,d,EL)/AELFG(q,d,EL)$. Thus, we can think of total land for dry non-livestock industries as being hectares adjusted for productivity or weather conditions. With a low value for $\sigma(q,d)$ in (13) we are assuming that the amount of operator labour required in a dry non-livestock industry for a given amount of hectares moves with the productivity of the land: more operator labour is needed per hectare in good seasons than in bad seasons.

Finally, what does the adoption of a low value for $\sigma(q,d)$ in (13) mean for dry livestock industries? These industries have the extra complication of total land input being formed by feed grain as well as productivity-adjusted effective land. In approximate terms, a low value for $\sigma(q,d)$ in these industries means that we need a fixed amount of operator labour per unit of fodder-supplied land where fodder encompasses both pasture and feed grain.

3.5 The cost of using different types of land and the demand for irrigation water

Under our Leontief assumption, industry (q,d) 's demands for irrigation water and unwatered irrigable land are simply proportional to the industry's demand for irrigable land, $XLN(q,d,LNI)$. The Leontief assumption also allows us to relate the cost to industry (q,d) of using irrigable land to the rental value of unwatered irrigable land and to the price in region d of irrigation water via the equation:

$$PLN(q,d,LNI) = PLNR(q,d,LNI) + C(q,d,LNI) * PW(q,d) \quad , \quad (15)$$

where

$PLNR(q,d,LNI)$ is the rental rate applied to unwatered irrigable land used by (q,d) ;

$PW(q,d)$ is the price or value per unit of irrigation water to industry (q,d) ; and

$C(q,d,LNI)$ is the technologically determined use of irrigation water per hectare of unwatered irrigable land in industry (q,d) . Its value is close to zero if q refers to a dry-land industry.

⁴ More accurately, the high value of $\sigma_{in}(q,d)$ means that $XELFG(q,d,EL)$ is approximately a linear combination of $XLN(q,d,LNI)$ and $XLN(q,d,LND)$. It is approximately the sum of land inputs to (q,d) where a unit of land of type k is defined as the area that had a rental value in (q,d) of \$1 in the data for our base period.

In percentage change form for inclusion in TERM-H2O, (15) is written as:

$$\begin{aligned} \text{PLN}(q, d, \text{LNI}) * \text{pln}(q, d, \text{LNI}) = & \text{PLNR}(q, d, \text{LNI}) * \text{plnr}(q, d, \text{LNI}) \\ & + \text{C}(q, d, \text{LNI}) * \text{PW}(q, d) * \text{pw}(q, d) \end{aligned} \quad (16)$$

where the lowercase symbols are percentage changes in the variables denoted by the corresponding uppercase symbols.

As mentioned already, for dry-land industries we use variations in $\text{AELFG}(q, d, \text{EL})$, appearing in (8), to represent variations in rainfall. In simulations in which climatic conditions are ideal in region d , $\text{AELFG}(q, d, \text{EL})$ is set at one for dry-land industries. In simulations representing severe drought conditions $\text{AELFG}(q, d, \text{EL})$ may be set as high as 5. For irrigated industries $\text{AELFG}(q, d, \text{EL})$ will normally be set at one: under our assumption that $\text{C}(q, d, \text{LNI})$ is determined technologically, variations in climatic conditions affect the quantity of irrigable land that is used by irrigated industries but not the productivity of that land.

In section 4 we discuss the region-wide constraints applying to operator labour, irrigable land, dry land and physical capital.

4. Region-wide constraints and the determination of rental rates for factors and prices for water

4.1 Determination of rents

We assume that each region d has available fixed amounts of the factors unwatered irrigable land, dry land, operator labour and agricultural capital, that is there is a fixed amount of each f in the set $\{\text{UWLNI}, \text{LND}, \text{OP}, \text{K}\}$. For each f , TERM-H2O allocates this fixed amount between the $\text{H}(d)$ farm industries in region d in a price sensitive way according to the optimization problem

$$\begin{aligned} \text{choose} \quad & Z(q, d, f), q = 1, 2, \dots, \text{H}(d) \\ \text{to maximize} \quad & \sum_q \text{PZ}(q, d, f) * Z(q, d, f) \end{aligned} \quad (17)$$

$$\text{subject to} \quad \text{ZTOT}(d, f) = \text{CET}_q(Z(q, d, f)) \quad (18)$$

where

$Z(q, d, f)$ is the supply of factor f to industry (q, d) ;

$\text{ZTOT}(d, f)$ is a measure of the total quantity of factor f available in region d ; and

$\text{PZ}(q, d, f)$ is the rental rate for factor f when used by industry (q, d) . In section 4, $\text{PZ}(q, d, \text{UWLNI})$, $\text{PZ}(q, d, \text{LND})$ and $\text{PZ}(q, d, \text{OP})$ were denoted as $\text{PLNR}(q, d, \text{LNI})$, $\text{PLN}(q, d, \text{LND})$ and $\text{PTLOP}(q, d, \text{OP})$.

Optimization problems (17) - (18) give TERM-H2O percentage change equations describing the supply of factors to industries. These equations take the form:

$$\begin{aligned} z(q, d, f) = & \text{ztot}(d, f) + \tau(d, f) * (\text{pz}(q, d, f) - \sum_v \text{R}(v, d, f) * \text{pz}(v, d, f)) \quad , \\ & \text{for all } (q, d) \text{ and } f, \end{aligned} \quad (19)$$

where

$z(q,d,f)$, $z_{tot}(q,d,f)$ and $p_z(q,d,f)$ are percentage changes in the variables denoted by the corresponding upper-case symbols;

$R(v,d,f)$ is industry (v,d) 's share of the total rental value of factor f in region d ; and

$\tau(d,f)$ is a positive parameter (transformation elasticity) that reflects the ease with which factor f can be moved between industries in region d .

With demands specified through the optimization problems set out in section 2, and with supplies specified through the optimization problems set out in this section, TERM-H2O determines rental rates via market-clearing equations:

$$XTLOP(q,d,OP) = Z(q,d,OP) \quad , \text{ for all } (q,d) \quad (20)$$

$$XLOKH(q,d,K) = Z(q,d,K) \quad , \text{ for all } (q,d) \quad (21)$$

$$XLN(q,d,LNI) = Z(q,d,LNI) \quad , \text{ for all } (q,d) \quad (22)$$

$$XLN(q,d,LND) = Z(q,d,LND) \quad , \text{ for all } (q,d) \quad (23)$$

4.2 Determination of the price of irrigation water

Industry (q,d) 's supply and demand for irrigation water is given by:

$$ZW(q,d) = AW(q,d) + TRADE(q,d) \quad (24)$$

and

$$XW(q,d) = [C(q,d,LNI) - NatW(d)] * XLN(q,d,LNI) \quad (25)$$

where

$ZW(q,d)$ is the supply of irrigation water in industry (q,d) ;

$AW(q,d)$ is the amount of irrigation water allocated to (q,d) via the irrigation system;

$NatW(q,d)$ is the amount of irrigation water supplied to (irrigation industries in region d through rainfall;

$TRADE(d)$ is the net amount of irrigation water obtained by region d from trade with other regions;

$XW(d)$ is the demand for irrigation water in region d ; and

the remaining notation in (25) is as defined earlier.

Market clearing for irrigation water means that

$$XW(d) = ZW(d) \quad . \quad (26)$$

In TERM-H2O, the prices of irrigation water [$PW(d)$] adjust to achieve (26).

To allow for different water trading regimes we include in TERM-H2O equations of the form:

$$PW(d) = \sum_{g=1}^G \text{Dummy}(d,g) * PWG(g) \quad \text{for all } d \quad (27)$$

and

$$\sum_d \text{Dummy}(d,g) * \text{TRADE}(d) = 0 \text{ for all } g \quad (28)$$

where

G is the number of groups of regions that form separate water trading blocks;

PWG(g) is the price of irrigation water in trading group g; and

Dummy(d,g) = 1 if d is in trading group g and zero otherwise.

If no trade is possible between regions, then G is simply the number of regions and (27) and (28) reduce to:

$$\text{PW}(d) = \text{PWG}(d) \text{ for all } d \quad (29)$$

and

$$\text{TRADE}(d) = 0 \text{ for all } d \quad (30)$$

If trade is possible between all regions, then G= 1 and (27) and (28) reduce to:

$$\text{PW}(d) = \text{PWG}(1) \text{ for all } d \quad (31)$$

and

$$\sum_d \text{TRADE}(d) = 0 \quad (32)$$

If there are two water trading groups, one consisting of regions 1 to R_1 and the other consisting of regions R_1+1 to R, where R is the number of regions, then (27) and (28) reduce to:

$$\text{PW}(d) = \text{PWG}(1) \text{ for all } d= 1, \dots, R_1 \text{ and } \text{PW}(d) = \text{PWG}(2) \text{ for all } d= R_1+1, \dots, R \quad (33)$$

and

$$\sum_{d=1}^{R_1} \text{TRADE}(d) = 0 \quad \text{and} \quad \sum_{d=R_1+1}^R \text{TRADE}(d) = 0 \quad (34)$$

5. Database amendments

The published IO tables released by ABS distinguish 109 sectors. In the context of irrigation, this is insufficient to distinguish between differences in water intensity of different irrigation activities. Some of the main irrigation crops, namely grapes, cotton, fruit and vegetables are represented by a single composite sector (i.e., other agriculture) in the published table. Therefore, the first step in regional database preparation procedure was to split the national database to sectors of interest.⁵

The next step was to choose a suitable base year. Although tables have been released for 2004-05, we chose to update to 2005-06. Our motivation was that this was the last of the years in which irrigation water in south east Australia was relatively abundant. In addition, this enabled us to align the national database with the 2006 census, from which we obtained census data at the three-digit ANZSIC level for services and at the four-digit level for other sectors. ABS census data includes employment by industry for each of

⁵ In addition to splitting various agricultural sectors, the national IO table was also split to represent mining, electricity generation, health, education and other services sectors in greater detail.

1400+ statistical local areas. ANZSIC data supplement ABS agricultural output represents grapes, fruit trees, rice and cotton as individual sectors, thereby enhancing versions of TERM dealing with irrigation sectors and water accounts.

To update the extended national database, we used the ADJUST program.⁶ With this program, we target known values of key variables in the database while retaining balance. That is, costs must equal sales for each sector, implying that GDP is equal on the income and expenditure sides. The required inputs are broad sectoral value-added data and expenditure-side macro values from ABS national accounts, plus international export and import data at the four digit ANZSIC level.

The regional master database on which TERM-H2O is based represents the Australian economy at the statistical sub-division level containing 206 regions (that is, we aggregate data from the census for 1400+ regions to 206 regions). Each of these regions has its own input-output structure and inter-regional trade matrices at a highly disaggregated level in the sectoral dimension. The motivation for this representation is that it allows us to cover many of the hot topics in Australian policy analysis, including water. In the case of water, the statistical sub-divisions of the Murray-Darling basin align quite well with catchment regions.

In practice, we undertake two sets of aggregations from the 172 sector, 206 region master database to prepare the TERM-H2O database. First, we aggregate the master database to 28 sectors, with an emphasis on irrigation sectors (that is, 10 of the 28 are farm sectors) and 46 regions, representing the regions of the Murray-Darling basin at the statistical sub-division level (40 regions) with more aggregated regions for the rest of Australia (6 regions).

With the 28 sector, 46 region database, the first step is to split farm sectors into irrigation and dry-land sectors. Following this step, we have 35 industries producing 28 commodities, with seven farm outputs being produced by each of two industries, dry-land and irrigated. We split dairy cattle, cotton, non-dairy livestock, cereals, fruit, sugar cane and other agriculture into dry land and irrigated sectors. We assigned rice, vegetables and grapes as exclusively irrigation activities. Supplementary data made the split of cotton and sugar cane into irrigated and dry land sectors relatively straightforward (ABS 2007). We assumed that most dairy holdings include some irrigated and some dry land activity. In the case of irrigated cereals, we inferred yields from water application per hectare data provided by ABS, to obtain an estimate of production. The most difficult sector to split was non-dairy livestock. Although this sector traditionally has been a broadacre activity, irrigation and feedlot production is growing. A further complication is that a growing input to the sector is irrigated pasture, which is not represented separately in the published input-output table. ABS Agstats data on the number of irrigated hectares in grazing and cropping by statistical division are not useful, as they imply widely varying water application rates per hectare. Despite the weakness of available data for some sectors, the alignment of ABS water data to agricultural sectors has improved with successive publications of the water accounts.

⁶ The archive item www.monash.edu.au/policy/archivep.htm TPMH0058 contains the ADJUST program used in this procedure.

For irrigated sectors, we use available water accounts (ABS 2006b; ABS 2007) which provide estimates of water use by industry at the state level. Water volumes in these accounts include water extracted from the environment via mains supplies, rivers and farm dams, but not direct rainfall. The next step is to allocate water usage by industry to the regional level. Fortunately, most production of two of the largest users of water, namely rice and cotton, is confined to a handful of regions, as indicated by census data. This simplifies estimating water usage at the sub-state level from available state-level water accounts data. The ABS also provides water usage data separately at that state level for dairy cattle, grapes and vegetables. Remaining farm sectors include grains, non-dairy livestock, non-dairy pasture and other.

Finally, we had to account for the value of water in production in the database. The year on which we base TERM (2005-06) was the most recent of the years in which water was relatively abundant. Given this, in the TERM database, we assigned a relatively low initial unit value to water used by irrigators, \$30 per megalitre. This is consistent with average prices reported for temporary trades in Victoria and New South Wales in 2000-01 (ABS 2004, figure 11.1 and Table 21.5). Water's value is based on the initial price multiplied by the estimated volume of usage. We had to reassign primary factor values in each irrigation industry so as to account for the value of water.⁷ Water rights may be embedded in the industry GOS. We adjusted primary factor returns so as to include the cost of water in irrigated sectors. Natural rainfall is also embedded in GOS but requires no adjustment. We distribute 50% of the remaining GOS to each of owner-operators and irrigated land. A negligible value is assigned to dry-land rentals. Given the unit cost of water imposed above, primary factor cost shares for water are around 20% in the irrigated dairy cattle sector, 10% in the irrigated cotton sector and around 50% in the rice sector.

In dry-land sectors, we allocated the initial returns to land half each to the dry-land factor and owner-operators. In order to implement CES substitution between feed grains and pasture, no adjustment is required to the database. We interpret the feed grain usage in the livestock sectors in the published input-output table as that of a typical (i.e., not in drought) year.

To solve TERM-H2O, it is necessary to aggregate the regions of the master database to the regional focus of the study. The aggregation used in this application concentrates on the southern Murray-Darling basin and includes 22 regions.

6. Additional features: the impacts of water trading and constraining trade

6.1 Irrigation water price equalisation

We are able to ascribe a shock in isolation in TERM-H2O that does nothing other than allow water trading to equalize water prices across the trading region. The following solves for the price of water in the southern Murray-Darling basin:

$$0.01 * PW(q,d) * pw(q,d) = -PW0(q,d) * delUnity + delwatall \quad (35)$$

⁷ Dixon *et al.* (2007) in a report on an earlier version of the model, simulating the 2006-07 drought, compared modelled post-simulation water prices with those reported by water trading authorities.

In the above, $PW_0(u,d)$ is the initial water price for each irrigation sector in all regions of the southern Murray-Darling basin. With delwatal exogenous, a homotopy shock (denoted by a shock of 1 to delUnity) results in $\text{pw}(q,d)$ adjusting in each sector so that the updated level $PW(q,d)$ is equal for all users.

6.2 *Constraining the volume of water traded*

Within the theory of TERM-H2O, there are two sources of water for irrigation sectors, both irrigation water and rainfall. If the marginal product of water for a sector is lower than for other irrigation sectors, that sector will sell water to others. It is possible that the value of water will not be equalized across all irrigators before that sector has exhausted its irrigation water. Without a constraint on trade, the theory of the model permits a sector to sell part of its rainfall, which is impossible in practice, implied by irrigation water usage turning negative.

To circumvent this problem, we have added a complementarity condition to TERM-H2O for some irrigation sectors. Harrison *et al.* (2004) describe the implementation of complementarities within GEMPACK software. A complementarity allows us to impose a constraint on the volume of water traded. The simplest rule would be to set the limit to a sector's exports of water equal to its irrigation water availability, but there may be engineering constraints on the volume that it is possible to trade. The Barmah choke in the southern Murray-Darling basin is an example. The complementarity allows one of two conditions: either the volume of water traded is below the limit, and the constraint is not binding, or the limit is reached and the constraint is binding. In the case of the former, the price of water to all users is equalized within a feasible water trading region. In the latter, the binding constraint acts as tax on trade, keeping water trade volumes to the limit and reducing the marginal price of water in the sector that has reached the constraint by making a water trading tax endogenous. This tax is returned to users so as to keep the price of water for a low value use below the trading price.

In defining the constraint applicable to each water trader, we need to remember that water allocations are endogenous to seasonal conditions. Therefore, the constraint must be in a form that is endogenous overall, while retaining an exogenous variable that we can shock to vary the severity of the constraint. A suitable variable to be exogenous is the ratio of permissible water volume traded to water availability ($\text{TRD_WAT_PER}(q,d) = \text{PERMVOL}(q,d)/\text{ZW}(q,d)$, where endogenous $\text{PERMVOL}(q,d)$ is the permissible trading volume), with a default value of 1.0.

In addition to writing the complementarity condition into the model code (following Harrison *et al.*, 2005), we need to amend (35) as follows:

$$[0.01 * PW(q,d) * T(q,d)] * (\text{pw}(q,d) + t(q,d)) = -[PW_0(q,d) * T_0(q,d)] * \text{delUnity} + \text{delwatal} \quad (36)$$

In the above T_0 is the initial level of the power of the water trading tax, and T the updated power of the tax. When the complementarity constraint is binding, the equation

solves for $t(q,d)$. When it is not binding, $t(q,d)$ is unchanged and all the adjustment in the water price is via $pw(q,d)$.

7. Making TERM-H2O dynamic

Some policy applications are readily undertaken using a comparative static CGE model. An example is the short-term impacts of drought, as depicted with an earlier version of TERM-H2O (Dixon *et al.*, 2007). The Commonwealth's buyback scheme will proceed gradually over a number of years. The importance of this is that there may be significant technological change by the time the Commonwealth's target of water purchases is complete. Therefore, water taken out of the southern Murray-Darling basin over time may be compensated in part by technological changes that reduce the water and other input requirements of various irrigation activities per unit of output. Moreover, the Victorian government is currently undertaking irrigation infrastructure upgrades, particularly in the Goulburn Valley, which will increase effective water availability by reducing leakage and evaporation. Overall, an appropriate modelling approach is to compare the Commonwealth's buyback scheme with a baseline scenario that takes account of technological change over time, so as not to exaggerate effective water losses to irrigation arising from the buyback.

Following Dixon and Rimmer (2002), a dynamic form of TERM-H2O has been prepared for this application. At the heart of the theoretical modifications for dynamics is the link between annual investment flows and capital stocks. Investment makes up a substantial proportional of economic activity on the expenditure side and capital rentals a substantial proportion on the income side in the economy. This therefore is the most substantial of the flow and stock links. Another important link particularly for Australia with its large net foreign debt is that between current account flows (i.e., the trade balance and net interest payments to foreigners on existing debt) and net foreign liabilities. This link feeds into net disposable income, and the consumption function that links household spending to disposable income. We have not yet implemented dynamic links between water flows and reservoir stocks. Instead, we keep annual water allocations exogenous.

In dynamic applications, there are three sets of year-by-year simulations. The baseline forecast simulation takes forecasts of regional (state-wide) economic growth from forecasting agencies such as Access Economics (2007). Macro variables including regional real GDP, aggregate employment, aggregate consumption, aggregate investment and export volumes that are usually endogenous are targets, are made exogenous by a swap with various shift terms. For example, a state-wide level technological change term becomes endogenous so as to meet the state level real GDP forecast.

The baseline forecast scenario is rerun with a policy closure. That is, variables that are usually exogenous in policy simulations, such as state-wide technological change, are made exogenous and shocked by the endogenous change of the initial baseline simulation. The rerun simulation therefore includes a lot of shocks to various shifters that were endogenous in the forecast run so as to accommodate forecast targets. The policy simulation, which in our study concerns the Commonwealth's buyback scheme, includes all the shocks of the policy rerun simulation plus additional shocks specific to the scenario.

Another motivation for using a dynamic approach is to compare a policy scenario with different baselines. This study examines the Commonwealth's buyback scenario with drought. The inclusion of drought in the baseline is in response to the severity of the current prolonged drought affecting irrigation in south east Australia, as outlined in the introduction. Were we to run the scenario without drought, the main difference would be that the price paid for buyback water by the Commonwealth would be lower.

8. The Commonwealth buyback scenario

In our main scenario, the Commonwealth purchases 1500 gigalitres of water over an eight year period from irrigators in the southern Murray-Darling basin. Each year, purchases from holders of water rights are made in proportion to the size of each right. Since we allow full water-trading across the southern Murray-Darling basin (water is traded year-by-year until prices to all irrigators equalise across the region, unless the holder of a water right exhausts available water before price equalisation), the assumption of from whom the Commonwealth purchases is not critical. That is, if a particular user wishes to use more water having sold part of their water right to the Commonwealth, purchases from other holders of water rights are permitted. To model the payment to irrigators for buyback water, we add buyback purchases to the consumption function of each region.

Theoretical modification to deal with the buyback plan

Three main modifications have been made to TERM-H2O to deal with buyback scenarios. First, the quantity and implied value of buyback water have been added to the database, and water availability in each region is now calculated net of accumulated buyback volumes. Second, the value of buyback water purchases has been added to the consumption function of each region. This takes water out of production but gives the value of buyback purchases to original holders of water rights on an annualised basis. Third, a complementarity condition outlined in section 6 has been added to the model to impose a constraint on the volume of the water traded.

Since 1500 GL extracted from the SMDB over time represents a substantial share of irrigation water used in the region (around 33 percent, based on the 2005-06 ABS water accounts), the policy will have a significant impact on irrigation water prices. We have made the price paid by the Commonwealth endogenous, so that if water is exceptionally scarce in a particular year, the price paid is higher than in a year of relatively water abundance. We have abstracted from the distinction between permanent and temporary trades. Although the buyback will entail purchases of permanent water at a stock price rather than via annual payments to growers, within the model we treat payments as though they follow an annualised rule. If water is scarce in the year of purchase, both the annualised price and present stock price will rise for permanent water rights. We have modelled a return to near-normal allocations in the SDMB, with incremental increases in allocations in 2010 and 2011. These have the effect of reducing the annualised payments by the Commonwealth for buyback water in later years.

Aggregate results of buyback during drought

The drought baseline includes the usual assumptions of dynamic baselines, including technological change and underlying macro forecasts. In the context of this study, we

assume that irrigation water efficiency improves by 1.5 percent per annum. This implies that *effective* water (that is, water availability net of efficiency gains) changes less between the buyback endpoint and the starting year than if there were no water efficiency gains over time.

In the scenario, buybacks commence in 2008 and continue over an eight year period until 1500 GL have been purchased by the Commonwealth. Our first task is to compare real GDP at an aggregate level for the SMDB with a back-of-the-envelope (BOTE) calculation. 1500 GL accounts for around 26 percent of water inclusive of water rights and rain in irrigation enterprises in the SMDB in 2017. In turn, the value of water used in SMDB irrigation in the TERM-H2O database is 0.58 percent of SMDB GDP. Therefore, a first guess is that buyback purchases will reduce SMDB's real GDP by 0.15 percent ($=0.258 \times 0.58\%$). The modelled deviation relative to forecast in real GDP in the year 2017 is -0.058 percent. Our first task is to examine why the loss in real GDP is much less than our BOTE calculation. Before this, we note that deviations in employment (a rise of 0.005% across SMDB) and capital (-0.008%) from forecast do not explain the discrepancy as their joint impact on real GDP is close to zero. We need to examine how resource movements have alleviated income losses.

The first column in table 1 shows the impact of buyback on irrigation outputs in the SMDB relative to no buyback in 2017. For individual sectors in which output declines, there is a greater than proportional decline in water used as its scarcity worsens. Irrigated cereal crops provides the example of the largest water saving, with 51% of base case water (i.e., -49%) being used to produce 67% of base case output, as producers substitute away from water in response to rising water prices. The price of water rises by 31% compared with the primary factor composite price rise of only 0.8%.

The third column indicates the relative water-intensity of each sector, measured in gigalitres of water used per million dollars of value-added (pre-simulation). The responsiveness of a sector to rising water prices depends substantially on this measure of water intensity. Irrigated cereal has a close substitute (dry land cereal), making it highly responsive to changes in water scarcity.

The fourth and fifth columns of table 1 show the contribution of each irrigation sector to SMDB's overall irrigation output and water usage. Irrigated cereal contributes 5.0% of the total irrigation output reduction of 7.2% (fourth column), in line with its contribution to water usage reductions of 17.7% out of 25.8% (fifth column). For each sector shown in table 1, the fall in $xwat$ (% change in water usage) is larger than $xtot$ (% change in output) due to substitution away from water as its price rises.⁸ In addition to substitution, there is compositional change. Without water trading, each sector would reduce its water usage by 25.8%: water would not move to relatively more valuable uses and overall irrigation output would decline by more than 7.2%.

⁸ This substitution arises through a rise in the relative price of the land-water composite in equation (13).

Table 1: Irrigation sectors in SMDB, output and water usage^a

	xtot%	xwat%	GL/value-added \$m	contxtot%	contxwat%	pwat%	pprim%
Cereallrig	-33.2	-49.1	4.1	-5.03	-17.7	31.2	0.8
Rice	-21.8	-29.1	8.3	-0.99	-6.2	31.2	16.9
DairyCatIrig	-1.9	-4.1	0.9	-0.55	-0.6	31.2	0.9
OthLivstoIrg	-9.7	-16.0	1.8	-0.37	-0.6	31.2	-0.1
CottonIrig	-2.2	-5.2	1.1	-0.04	-0.1	31.2	0.5
Grapes	-1.1	-4.0	1.1	-0.12	-0.3	31.2	2.3
Vegetables	0.3	0.6	0.4	0.01	0.0	31.2	0.1
FruitIrig	0.3	0.8	0.2	0.08	0.0	31.2	-0.1
OthAgriIrig	-18.3	-23.4	2.7	-0.19	-0.4	31.2	-0.2
Total	-7.2	-25.8		-7.2	-25.8	31.2	1.3

^a Results shown as % difference between 2017 policy and base case. xtot = output, xwat = water used in irrigation, contxtot = industry contribution to irrigation output, contxwat = industry contribution to change in water used, pwat = water price, pprim = composite factor price.

Table 2 summarises the impact of the buyback policy on irrigation outputs in the MDB relative to the drought baseline. The table also includes the change in water requirement per unit of output for irrigation sectors, and the change in irrigation water used per unit of output. The changes follow a general pattern that relatively water-intensive sectors tend to reduce irrigation water used in larger proportions than other sectors.

Table 3 shows the impact of the buyback scenario on water trading. The largest single change induced by the policy is in sales from irrigated cereal in North Goulburn to irrigated dairy cattle. Rising water scarcity induced by the buyback explains the movement out of water-intensive irrigated cereal production.

Macro results

At the macro level, the expected impact is for the buyback to reduce real GDP in irrigation regions. This is so in all regions other than North Goulburn and South Goulburn. In measuring real GDP in each region, we treat net water sold to other irrigators as an income source. In these two regions, the rise in the price of water due to buyback results in real GDP gains as water is exported.

We show the policy deviations in real GDP for New South Wales (figure 3a), the eastern irrigation regions of Victoria (figure 3b) and the western Victorian irrigation regions plus South Australia (figure 3c). Table 4 gives us a hint as to which regions will have the largest impacts from buyback. For example, Central Murray has a large share of both irrigation and total agriculture in regional value-added. Central Murray's real GDP falls more than in any other region due to buyback.

Table 2: Output and unit water requirement by irrigation sector
(% change, 2017 policy relative to 2017 forecast)

Output	WagCntMrm	LMrmb	AlbUpMrry	CentMrry	MrryDrIng	FarWest	MidWMalee	EMalee	BndNthLod	SthLoddon	ShepNGoul	SGoulbur	SWGoulbu	Wodonga	WOvnsMrry	EOvensMur	MurrayLnds
Cereallrig	-16.7	-9.8	-20.8	-10.6	-40.2	-44.4	-47.8	-36.6	-49.4	-38.8	-68.8	-58.0	-59.5	..	-38.0	..	-28.1
Rice	-32.0	-26.6	..	-26.8	..	..	19.8	14.4	..	..	21.5	15.1	14.3	14.2	14.3	13.5	23.2
DairyCatIrig	-4.1	-2.7	-4.4	-2.8	-3.2	1.4	-2.5	-2.1	-2.9	-2.7	-1.6	-2.2	-2.6	-2.4	-2.5	-2.4	0.0
OthLivstoIrg	-16.0	-14.5	-16.6	-12.9	-12.5	-13.4	-7.3	-5.7	-8.8	-6.5	-6.7	-5.9	-6.8	-6.2	-6.2	-6.0	-4.3
CottonIrig	..	-2.7	..	2.9	-3.7	-4.2	..	..	..	..	..	..	..	..	..	..	..
Grapes	-2.9	-1.6	-3.2	-2.0	-2.2	-2.8	-0.6	-0.4	-1.3	-1.4	-1.5	-1.9	-2.4	-1.1	-1.2	-1.1	-5.6
Vegetables	0.1	1.4	-0.5	1.0	0.6	1.3	-0.3	0.0	-0.7	-0.8	1.4	0.1	-0.7	-0.5	-0.6	-0.2	-0.2
FruitIrig	-0.1	0.7	-0.4	0.5	0.2	0.7	-0.2	0.0	-0.4	-0.5	0.7	0.0	-0.4	-0.3	-0.3	-0.1	-0.6
OthAgrIrig	-19.6	-12.7	-20.2	-13.3	-13.5	-14.7	-28.7	-21.0	-29.7	-22.5	-27.9	-21.5	-22.5	-22.2	-22.3	-21.8	-2.6
Water^a																	
Cereallrig	-21.0	-13.4	-25.4	-14.5	-45.0	-49.1	-52.2	-41.7	-53.7	-43.9	-71.6	-61.6	-63.1	..	-43.1	..	-32.9
Rice	-34.3	-29.0	..	-29.3	..	..	22.9	17.7	..	..	25.8	18.3	16.9	17.0	17.0	16.3	29.9
DairyCatIrig	-7.5	-5.1	-7.9	-5.6	-6.0	2.7	-4.9	-4.4	-5.6	-5.6	-3.4	-4.6	-5.4	-5.2	-5.3	-5.0	-0.4
OthLivstoIrg	-22.0	-20.3	-22.6	-18.6	-18.1	-19.3	-11.5	-9.7	-13.6	-11.1	-10.7	-10.1	-11.5	-10.6	-10.5	-10.3	-7.1
CottonIrig	..	-4.5	..	5.7	-5.9	-7.1	..	..	..	..	..	..	..	..	..	..	..
Grapes	-6.8	-4.6	-7.2	-5.5	-5.5	-6.7	-2.9	-2.6	-4.3	-4.5	-4.7	-5.3	-6.2	-4.2	-4.2	-4.0	-10.3
Vegetables	0.0	2.4	-1.0	1.6	1.1	2.5	-0.6	-0.1	-1.3	-1.6	2.3	0.0	-1.4	-0.9	-1.1	-0.5	-0.4
FruitIrig	-0.3	1.9	-1.0	1.1	0.7	1.9	-0.4	0.0	-0.9	-1.2	1.8	0.0	-1.1	-0.7	-0.8	-0.3	-1.1
OthAgrIrig	-24.2	-16.7	-24.9	-17.7	-17.7	-19.4	-33.6	-26.3	-34.7	-27.8	-32.9	-26.7	-27.8	-27.7	-27.7	-27.3	-3.6
Irig. Water^b																	
Cereallrig	-29.3	-18.9	-35.9	-20.1	-60.6	-67.3	-69.5	-55.1	-72.8	-59.5	-90.4	-80.6	-82.9	..	-57.3	..	-43.6
Rice	-39.9	-33.8	..	-34.0	..	..	27.6	20.8	..	..	30.2	21.7	20.1	19.9	20.0	19.1	36.2
DairyCatIrig	-13.4	-8.9	-14.3	-9.7	-10.5	4.8	-7.6	-6.6	-8.6	-8.3	-5.0	-6.8	-8.1	-7.5	-7.7	-7.2	-0.7
OthLivstoIrg	-30.5	-27.8	-30.9	-25.6	-25.0	-26.8	-15.8	-13.0	-18.2	-15.2	-14.1	-13.9	-15.7	-14.4	-14.4	-13.9	-9.6
CottonIrig	..	-5.6	..	7.0	-7.3	-8.6	..	..	..	..	..	..	..	..	..	..	..
Grapes	-8.7	-5.9	-9.3	-6.9	-7.0	-8.5	-3.6	-3.3	-5.8	-6.1	-6.6	-7.7	-9.1	-5.5	-5.5	-5.2	-12.5
Vegetables	0.0	3.4	-1.4	2.2	1.5	3.4	-0.8	-0.1	-1.8	-2.2	3.0	0.0	-1.9	-1.3	-1.5	-0.6	-0.5
FruitIrig	-0.3	2.4	-1.3	1.4	0.9	2.5	-0.5	0.0	-1.2	-1.5	2.2	0.0	-1.4	-0.8	-1.0	-0.4	-1.4
OthAgrIrig	-31.3	-22.0	-32.5	-23.0	-23.3	-25.3	-43.1	-33.4	-44.9	-35.9	-41.0	-34.4	-36.0	-35.2	-35.5	-34.5	-4.8

a Water requirement per unit output

b Irrigation water used per unit output

Table 3: Water traded
(GL change relative to baseline, accumulated 2008 to 2017)

Output	WagCntMrm	LMrmb	AlbUpMrry	CentMrry	MrryDrIng	FarWest	MidWMalee	EMallee	BndNthLod	SthLoddon	ShepNGoul	SGoulbur	SWGoulbu	Wodonga	WOvnsMrry	EOvensMur	MurrayLnds
Cereallrig	-12.8	-18.4	0.1	-14.0	3.9	1.3	53.6	16.0	18.9	0.5	436.4	70.7	8.7	0.1	1.0	0.2	3.8
Rice	5.8	-1.0	0.0	2.8	0.0	0.0	-1.4	-1.4	0.0	0.0	-2.1	-1.2	-1.0	0.0	-0.1	-0.1	0.0
DairyCatIrig	-2.3	-0.2	-2.5	-15.9	-0.1	0.0	-1.3	-38.0	-9.9	-0.7	-170.7	-3.3	-1.5	-6.2	-6.2	-14.5	-10.6
OthLivstoIrg	-1.0	-0.5	-0.3	-1.0	-0.2	-0.5	-0.9	-1.1	-1.6	-0.4	-3.1	-2.5	-1.3	-0.6	-1.1	-0.8	-6.1
CottonIrig	0.0	-10.5	0.0	0.0	-0.9	-2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grapes	-0.7	-16.6	-1.4	-1.9	-11.0	-0.8	-26.6	-13.0	-2.3	-0.4	-1.9	-2.0	-1.1	-0.6	-3.6	-0.5	-47.8
Vegetables	-0.2	-1.7	-0.2	-0.7	-0.4	0.0	-1.4	-1.4	-0.8	-0.2	-1.9	-0.4	-0.5	-0.2	-0.2	-0.2	-9.3
FruitIrig	-5.2	-12.2	-0.9	-2.0	-3.9	0.0	-7.0	-7.5	-1.7	-0.4	-19.9	-0.9	-1.8	-0.6	-0.9	-1.0	-31.8
OthAgriIrig	0.1	-0.8	0.2	-1.0	-0.1	-0.1	0.2	0.2	0.3	0.1	1.0	0.1	0.1	0.0	0.1	0.1	-0.1

Table 4: Shares of irrigation in regional value added
(%, base year 2006)

Output	WagCntMrm	LMrmb	AlbUpMrry	CentMrry	MrryDrIng	FarWest	MidWMalee	EMallee	BndNthLod	SthLoddon	ShepNGoul	SGoulbur	SWGoulbu	Wodonga	WOvnsMrry	EOvensMur	MurrayLnds
CerealDryL	3.7	4.0	2.0	5.4	2.3	0.1	8.6	6.3	1.4	0.1	0.6	0.6	0.0	0.0	0.4	0.1	1.7
Cereallrig	1.2	1.3	0.6	1.8	0.3	0.0	0.5	0.4	0.1	0.0	0.7	0.7	0.1	0.0	0.0	0.0	0.1
Rice	0.1	1.4	0.0	1.9	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
DairyCatDryL	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.8	0.1	0.0	0.9	0.1	0.0	0.1	0.1	0.6	0.1
DairyCatIrig	0.1	0.0	0.1	2.0	0.0	0.0	0.1	5.5	0.4	0.1	6.4	0.5	0.2	0.6	1.1	4.3	1.4
OthLivstoDry	3.7	3.3	3.9	6.0	4.0	2.2	2.8	5.0	2.8	1.4	4.1	11.7	4.6	1.9	6.0	7.1	6.5
OthLivstoIrg	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.0	0.1	0.4	0.2	0.1	0.2	0.2	0.6
CottonDryL	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CottonIrig	0.0	0.7	0.0	0.0	0.3	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Grapes	0.0	1.0	0.1	0.2	3.6	0.1	2.2	1.9	0.1	0.0	0.1	0.3	0.1	0.1	0.6	0.1	2.1
Vegetables	0.0	0.3	0.0	0.2	0.4	0.0	0.3	0.5	0.1	0.0	0.1	0.2	0.1	0.0	0.1	0.1	1.2
FruitDryL	0.1	0.4	0.0	0.1	0.6	0.0	0.1	0.3	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.1	0.6
FruitIrig	0.6	2.9	0.1	0.7	4.8	0.0	2.1	3.7	0.2	0.2	2.5	0.5	0.7	0.2	0.5	1.0	4.9
OthAgriDry	0.5	0.9	0.7	2.3	0.7	0.2	0.5	2.2	0.4	0.8	1.1	2.6	1.1	0.1	0.6	1.4	0.1
OthAgriIrig	0.1	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total irig	2.2	7.1	1.1	7.2	9.3	0.2	5.4	12.3	1.0	0.3	9.9	2.7	1.5	1.0	2.5	5.7	10.3
Total farm	10.2	16.5	7.7	21.3	17.3	2.9	17.6	26.9	5.7	2.6	16.8	17.7	7.2	3.1	9.6	15.0	19.4
VWATER% ^a	0.42	1.56	0.21	2.03	0.82	0.07	0.47	0.85	0.09	0.02	0.99	0.53	0.10	0.07	0.18	0.39	0.76

^a VWATER% = pre-simulation water value as % of GDP

Figure 3a: Real GDP deviation (%), New South Wales

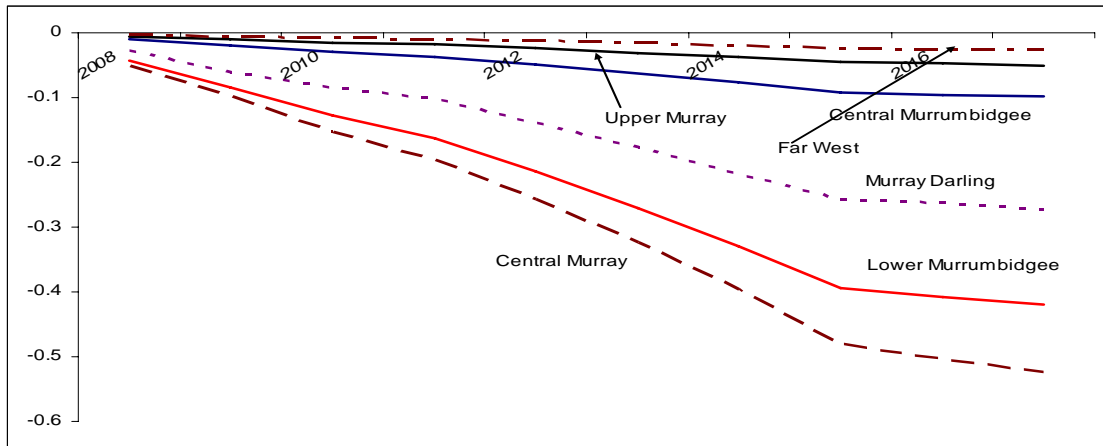


Figure 3b: Real GDP deviation (%), Eastern Victoria

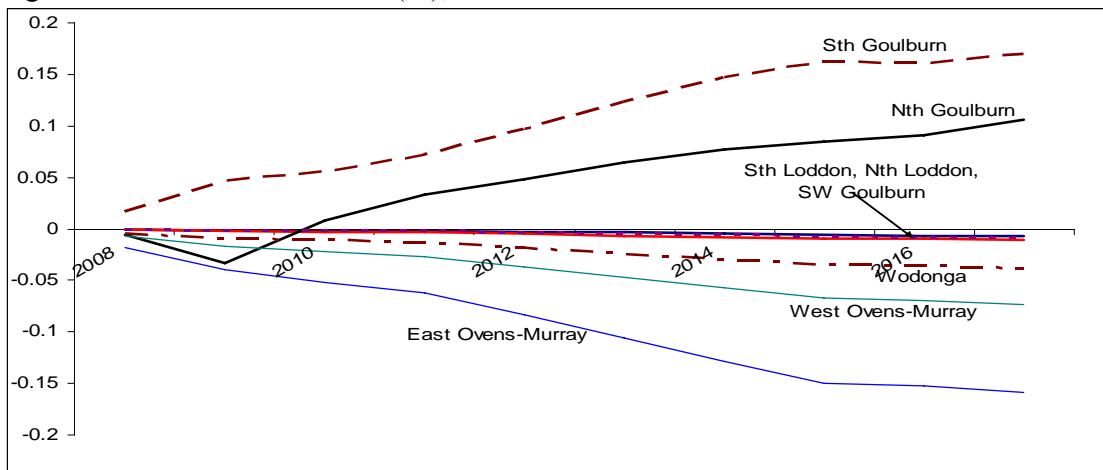


Figure 3c: Real GDP deviation (%), Western Vic & South Australia

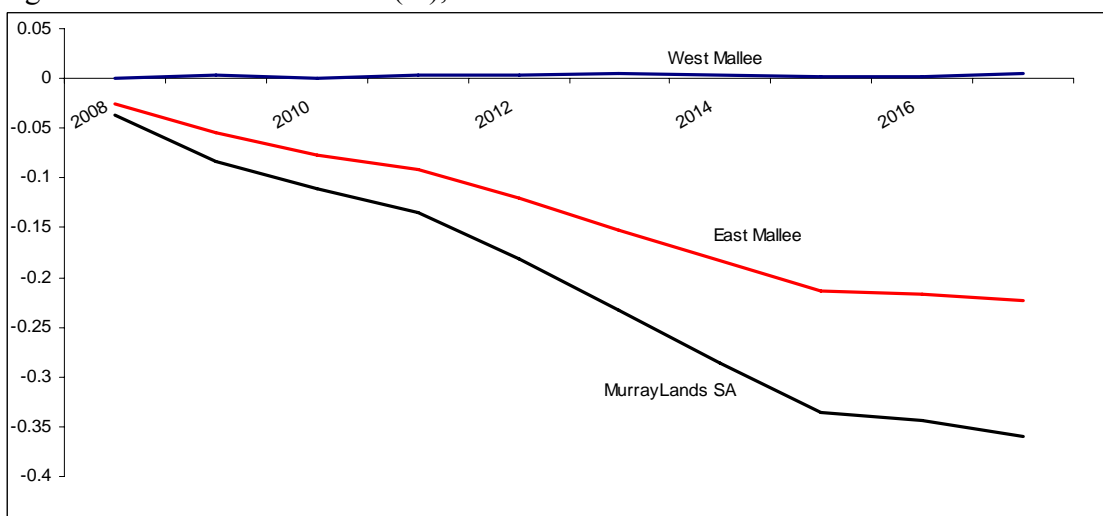


Figure 4a: Real consumption deviation (%), New South Wales

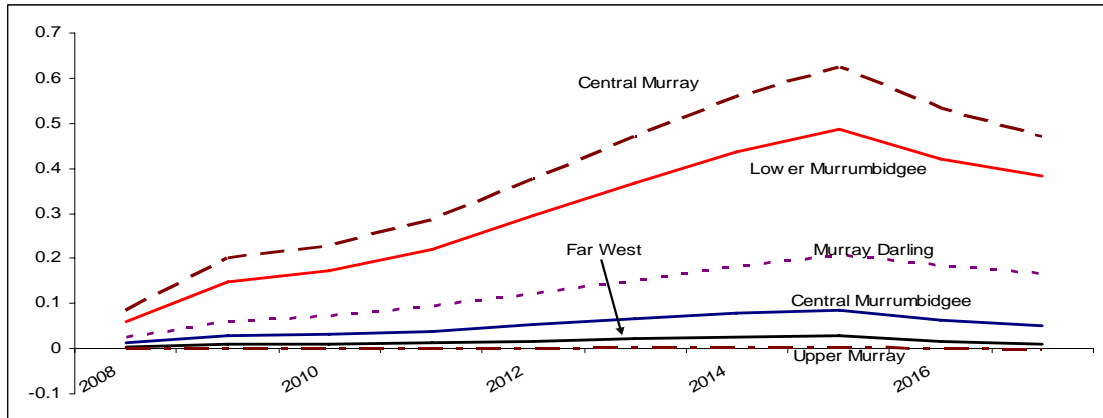


Figure 4b: Real consumption deviation (%), Eastern Victoria

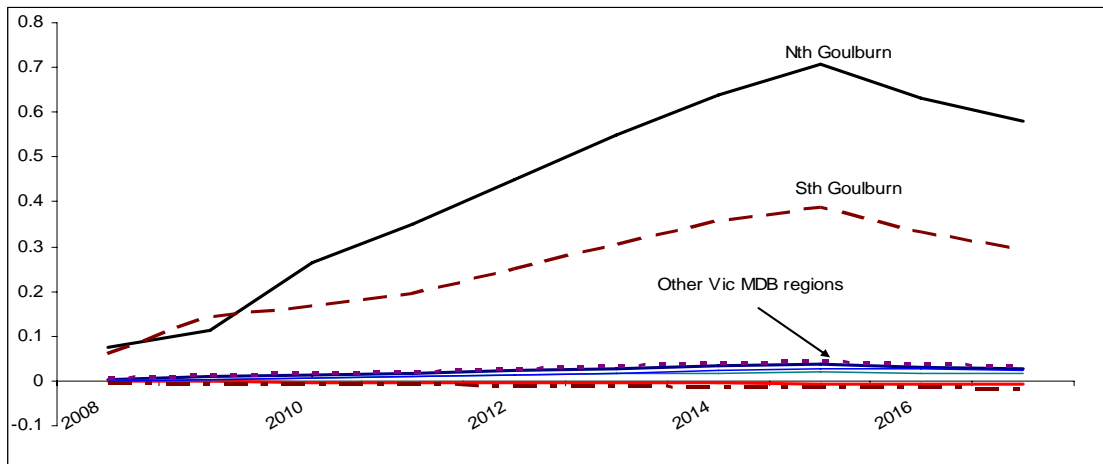
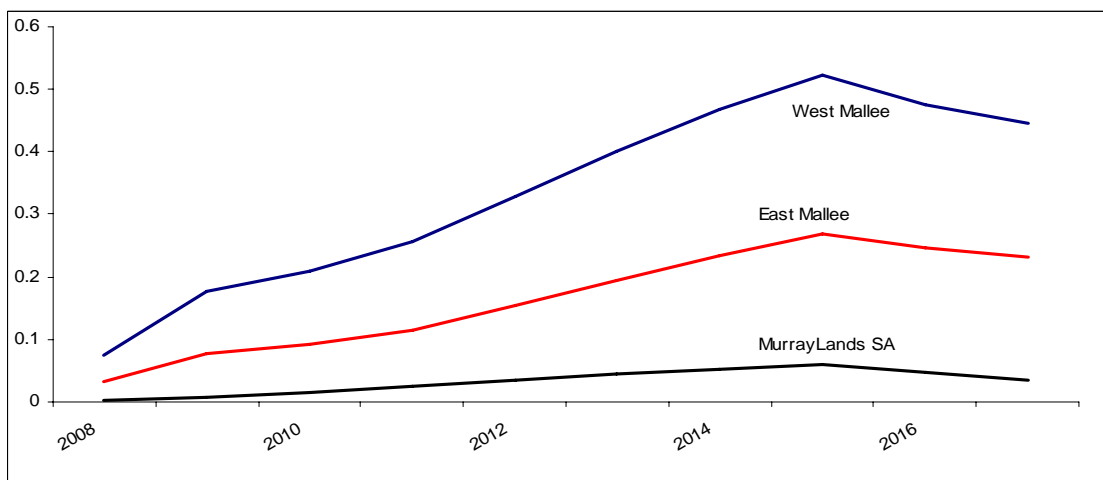


Figure 4c: Real consumption deviation (%), Western Vic & South Australia



A rather different picture emerges when we examine real consumption (figures 4a, 4b and 4c). The impact of buyback is to raise disposable income for regions with relatively large water allocations as a share of regional GDP. The rise in disposable incomes depends on farmers being paid a market price for water. Some of the largest losers in terms of real GDP are the largest winners in terms of the impact on aggregate consumption. For example, Central Murray NSW combines a loss in real GDP by 2017 of more than 0.5% with a gain in aggregate consumption of around 0.5%. The overall impact of the buyback scheme is to raise the asset value of water rights.

Scenario variants

One aspect of buyback not examined here concerns the different levels of security of various rights. At present, Victoria's irrigators tend to own higher security water entitlements than is the case in New South Wales. This implies that Commonwealth purchases are likely to be biased towards relatively secure Victorian rights. In modelling buyback scenarios against a background of drought, we could modify model shocks both to allow for a bias towards purchases of rights from Victorian irrigators and to ascribe greater water supply shocks to irrigators in regions and activities with less secure water entitlements. Taking account of differences in securities in further modelling will alter the pattern of water trading between regions and users in response to buyback.

Policy implications of the buyback modelling

Far from threatening regional economies in the Murray-Darling basin, the Commonwealth's buyback program may provide windfall gains to holders of water rights by raising the scarcity of water available for irrigation. This is evident in the impact of the buyback scheme on regional aggregate consumption (figures 3a, 3b and 3c). Even with the extreme assumption that no buyback revenue is spent in the region of origin, there would be little difference to the aggregation consumption outcomes, as buyback revenues represent a small proportion of aggregate consumption. The region with the highest buyback revenue to aggregate consumption share is Central Murray NSW, at 1.3% in 2017. This indicates that even if all buyback revenues leave the district, the potential downside of buyback at the regional level would be relatively small.

Another issue concerns the impact of buyback in the presence of drought. The buyback scheme may be potentially beneficial by enlarging the market for water during a period of drought-induced rural depression. The main cost of buyback in the context of drought will be to the Commonwealth, to the extent that drought raises the asset value of water rights. Moreover, the Commonwealth would be subject to the same fractional allocations as other water users during drought. This implies that during drought, the Commonwealth potentially would be spending more while having less water for environmental flows. From the perspective of both the environment and irrigators, with the benefit of hindsight, it would have been preferable to introduce environmental flows before the past decade of intermittent or continual droughts. This proved not to be possible under the slow and difficult process of policy evolution. Had there been a lower volume of highly secure irrigation allocations leading into the past decade, there would have been fewer farmers caught with insufficient water particularly for perennials, as investments in the latter would have decreased. Moreover, the Commonwealth could have sold temporary water back to irrigators during drought while allowing environmental flows during years of

relatively cheap water. The current dire circumstances still warrant Commonwealth purchases, to the extent that environmental flows now are able to mitigate irreversible ecological damage in the SMDB.

Perhaps the most important result from our modelling is that the impact of the buyback on regional economies is quite small. Moderate droughts and cuts in water allocations arising from drought have much greater impacts on regional economies in the SMDB than a buyback scheme conducted over a number of years. Droughts have had a negative effect on regional economies since the turn of the millennium, but even that has been far more pronounced in small towns than in larger regional centres. This is because rural regions too have followed a global trend that agriculture's share of an economy decreases with economic growth. To put this shrinkage into context, Australia at a national level was more agriculture intensive 60 years ago (over 25% of GDP in the late 1940s, Maddock and McLean, 1987) than the Central Murray NSW statistical sub-division is now (table 4). The vitality of regional economies in the future will depend much less on preserving existing water rights assigned to irrigation and more on regional provision of services, particularly in education, health and aged care, which already account for substantial shares of economic activity at a regional level.

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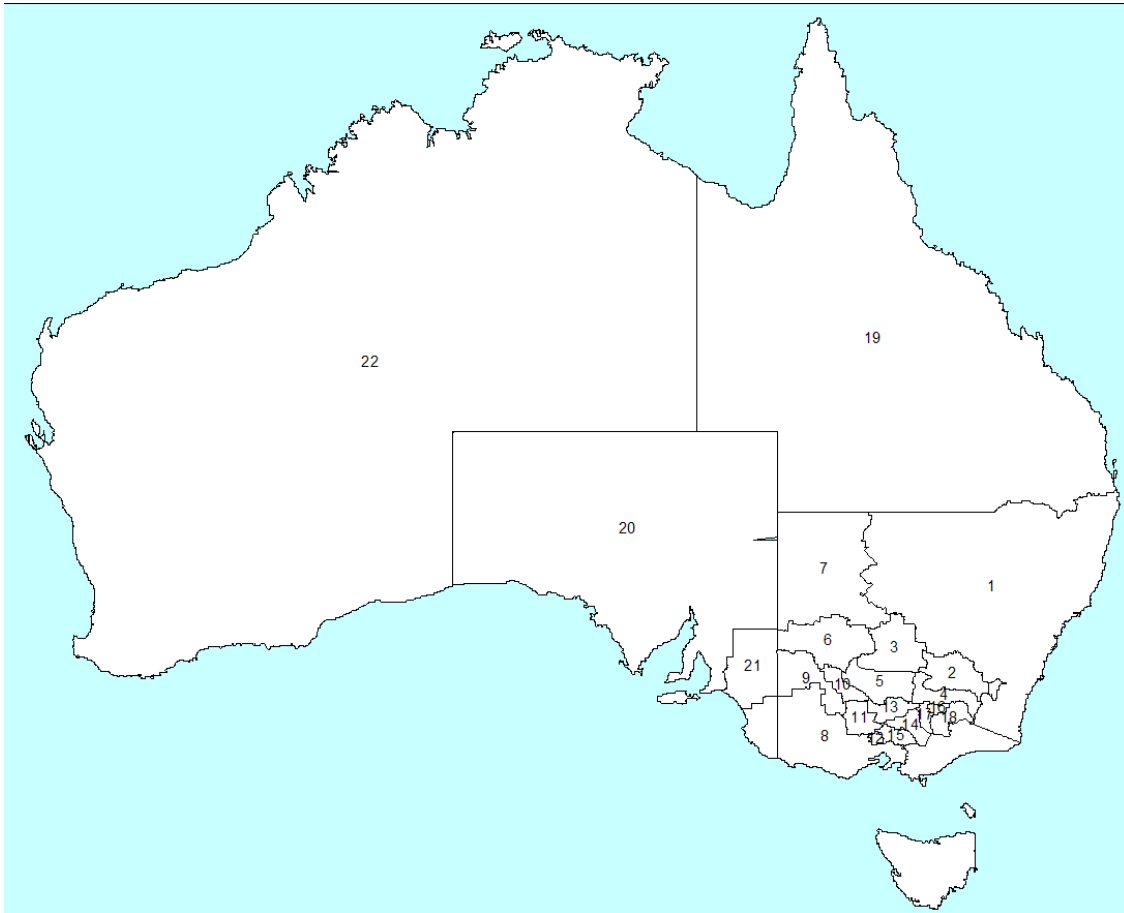
Appendix 1: Simulated buyback volumes by region and user

	CntMrmNSW	LMrmbNSW	UpMrryNSW	CentMrryNSW	MrryDrIngNSW	FarWestNSW
Cereallrig	85.2	39.0	30.1	34.6	3.8	1.0
Rice	32.2	150.0	0.0	136.4	0.0	0.0
DairyCatIrig	3.0	0.2	3.3	19.4	0.1	0.0
OthLivstoIrg	9.8	3.7	7.1	4.5	0.9	2.3
CottonIrig	0.0	12.7	0.0	0.0	1.2	4.1
Grapes	0.9	20.0	1.8	2.4	13.8	1.1
Vegetables	0.2	1.6	0.2	0.6	0.4	0.0
FruitIrig	5.3	11.4	0.9	1.9	3.8	0.0
OthAgriIrig	3.9	2.6	3.4	4.6	0.5	0.6
Total	140.5	241.2	46.8	204.4	24.5	9.1

	MldWMaleeVic	EMalleeVic	NthLodVic	SthLoddonVic	NGoulVic	SGoulburVic
Cereallrig	37.6	16.2	13.6	0.5	146.1	34.9
Rice	0.9	0.9	0.0	0.0	1.1	0.8
DairyCatIrig	1.5	44.0	11.8	0.8	191.4	3.8
OthLivstoIrg	1.8	2.0	4.3	0.7	6.1	4.3
CottonIrig	0.0	0.0	0.0	0.0	0.0	0.0
Grapes	29.8	14.5	2.7	0.5	2.4	2.6
Vegetables	1.4	1.4	0.8	0.2	1.8	0.4
FruitIrig	7.1	7.5	1.8	0.4	18.6	0.9
OthAgriIrig	0.3	0.8	0.6	0.4	1.5	1.0
Total	80.4	87.3	35.6	3.5	369.0	48.7

	SWGoulbuVic	WodongaVic	WOvnsMrryVic	EOvensMurVic	MurrayLndsSA
Cereallrig	4.2	0.2	1.0	0.2	6.8
Rice	0.6	0.0	0.1	0.1	0.0
DairyCatIrig	1.8	7.4	7.4	17.3	10.7
OthLivstoIrg	2.6	1.1	2.1	1.4	8.7
CottonIrig	0.0	0.0	0.0	0.0	0.0
Grapes	1.4	0.7	4.3	0.6	79.3
Vegetables	0.6	0.2	0.2	0.2	9.4
FruitIrig	1.8	0.6	0.9	1.0	33.1
OthAgriIrig	0.6	0.1	0.2	0.2	0.1
Total	13.6	10.3	16.2	21.0	148.1

Appendix 2: Map of regions in this aggregation of TERM-H2O



Regions: 1 Rest of NSW, 2 CntMrmNSW, 3 LMrbNSW, 4 UpMrryNSW, 5 CentMrryNSW, 6 MrryDrIngNSW, 7 FarWestNSW, 8 RoVIC, 9 MldWMaleeVic, 10 EMalleeVic, 11 NthLodVic, 12 SthLoddonVic, 13 NGoulVic, 14 SGoulburVic, 15 SWGoulbuVic, 16 WodongaVic, 17 WOvnsMrryVic, 18 EOvnsMurVic, 19 QLD, 20 RoSA, 21 MurrayLndsSA, 22 RoA.