

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](mailto: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**

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

## *Abstract*

TERM-H2O is a dynamic, multi-regional computable general equilibrium model of the Australian economy with agricultural detail adapted to include regional water accounts. It focuses on the effects of inter-regional water trading. Factors of production are mobile between sectors in farm industries. TERM-H2O 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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## *I Background*

The Council of Australian Governments (COAG) acted on the need for policy reform in the management of water in the southern Murray-Darling basin (SMDB) in 1994 (COAG 1994). At issue was the environmental health of the basin, and consequent doubts concerning the sustainability of irrigation, as well as the desire to move water to higher value uses. Among the reforms that followed was the disentanglement of water rights from land rights.

If the basin was in crisis in the mid-1990s, over a decade of below average rainfall in south east Australia since has worsened it. 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. Irrigation entitlements based on historical periods of higher rainfall have resulted in shortfalls in water allocations to irrigators. An important measure to reduce water allocations in the SMDB to sustainable levels is the Commonwealth's buyback scheme, which entails purchases of permanent water

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. Water purchased by the Commonwealth is for environmental flows, but extreme water scarcity since 2006 has confounded plans by reducing overall water availability. 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 to survive. In the wake of the 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. Water scarcity is providing a new crisis for the grape sector, which earlier in the decade suffered collapsing prices due to oversupply. Recognising the competing pressures on water in the basin due to drought, the Commonwealth and five state governments (NSW, Victoria, Queensland, South Australia and ACT) signed a new agreement (COAG 2008). This agreement aims to deal with sustainable diversion limits for irrigation, other industries and human needs. It also aims to deal with environmental flows, water quality and salinity management.

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 II to V 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. Section VI outlines additional features of TERM-H2O that deal with water trading and

constraints on the volume of water than can be traded. Section VII outlines the motivations for making TERM-H2O dynamic. The core policy scenario is analyzed in detail in section VIII. The paper concludes with a discussion of policy implications in section IX.

## *II 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. An industry's column of an input-output table shows its cost structure and a commodity's row shows its 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.

Figure 1 is a representation of 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. While each farm industry produces just one 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 -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. Section V provides more details on this split. 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.

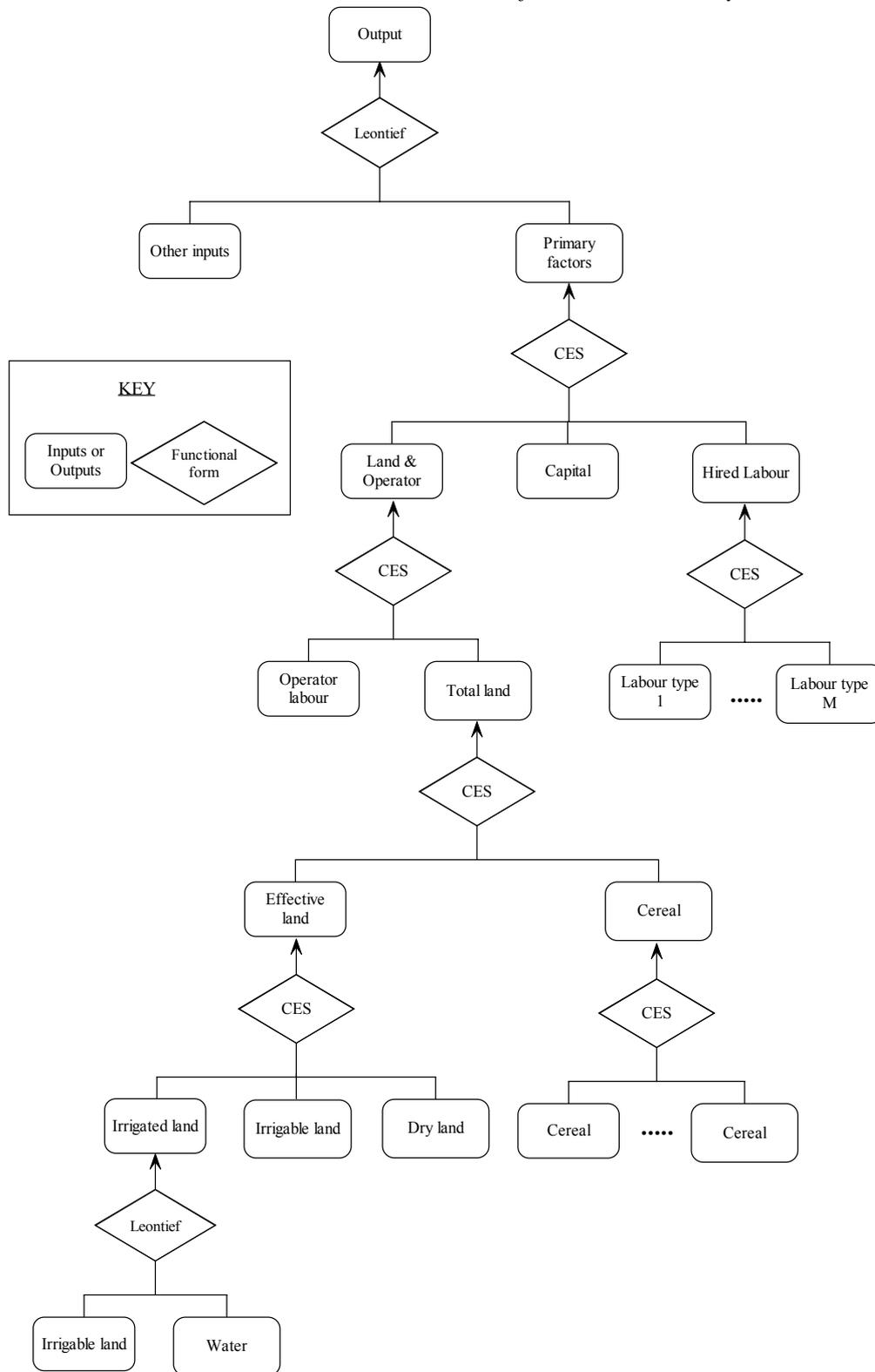
The rows of Figure 1 refer to values of inputs and outputs. The first  $N \times (R+1)$  rows (labelled Intermediate) are flows of  $N$  intermediate inputs to farm industries in region  $d$  from  $R$  regions of Australia and from abroad (imports). The next  $R+1$  rows refer to inputs that receive special treatment in TERM-H2O: cereals differentiated by region of supply and irrigation water. Cereals (including hay) are used as feed in dryland livestock industries. Irrigation water 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 and family); 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.

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)		
<b>Inputs</b>										
Intermediate, Nx(R+1)	Y	Y	Y	...	Y	Y	Y	Y	...	Y
Cereal including hay, R	-	-	-	...	-	√	√	-	...	-
Irrigation water	√	√	√	...	√	-	-	-	...	-
Capital	Y	Y	Y	...	Y	Y	Y	Y	...	Y
Hired labour, M	Y	Y	Y	...	Y	Y	Y	Y	...	Y
Operator labour	Y	Y	Y	...	Y	Y	Y	Y	...	Y
Dry Land	-	-	-	...	-	√	√	√	...	√
Unwatered irrigable land	√	√	√	...	√	√	√	√	...	√
Output	Total	Total	Total	...	Total	Total	Total	Total	...	Total

\* 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

FIGURE 2  
*Production Function for a Farm Industry*



### *III Production and input-demand functions for farm industries in TERM-H2O*

This section describes the production functions adopted in TERM-H2O. It then sets out the implied input-demand functions and shows how these are calibrated using data of the type represented in Figure 1.

#### *(i) Production functions*

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 modifications specific to TERM-H2O in the structure of  $(q,d)$ 's production function are 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 many goods. Each of these goods 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. This relatively standard treatment of intermediate inputs is not shown in detail in Figure 2, being part of "Other inputs".

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. 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 family) and of total land. There are then several nests below total land.

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

Effective land is shown in Figure 2 as a CES combination of irrigated land, unwatered irrigable land and dry land. For dry-land industries, the use of irrigated land is negligible. Thus, for these industries, effective land is a CES combination of only unwatered irrigable land and dry land. For irrigated industries, the use of unwatered irrigable land and dry land is negligible. Thus, for irrigated industries, effective land is simply irrigated land. The bottom nest concerns the input of irrigation water. We model this in a Leontief nest with unwatered irrigable land to form irrigated land. Thus we assume that irrigated land used by industry  $(q,d)$  is always fully watered.

Notice that unwatered irrigable land appears twice: in the nest below effective land and in the nest below irrigated land. TERM-H2O implies that a significant fraction of the available supply of irrigable land in any region is allocated as unwatered irrigable land to the region's dry-land industries when there are shortages of irrigation water. With reductions in water availability, TERM-H2O generates increases in the prices of irrigation water and

reductions in the rental values of unwatered irrigable land. This causes dry-land industries to increase their demands for unwatered irrigable land. At the same time, irrigated industries suffer cost increases causing them to reduce their demands for unwatered irrigable land. In this way, unwatered irrigable land is moved from irrigated industries to dry-land industries.

(ii) *Input demand functions*

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, dry land, operator labour and cereals.

*Demands for land*

First we examine the composition of the effective-land input. In deciding its inputs of irrigated land (LNI), unwatered irrigable land (LNUW) and dry land (LND) we assume that farm industry (q,d)

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

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

where

$\text{XLN}(q,d,k)$  refers to industry (q,d)'s inputs of land of type k (irrigated land, unwatered irrigable land or dry land);

$\text{PLN}(q,d,k)$  is the cost to industry (q,d) of using a unit of land of type k;<sup>1</sup> and

$\text{XELC}(q,d,\text{EL})$  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:

$$\text{PELC}(q, d, \text{EL}) = \frac{\sum_k \text{PLN}(q, d, k) * \text{XLN}(q, d, k)}{\text{XELC}(q, d, \text{EL})} \quad (3)$$

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:

$$\begin{array}{l} \text{xln}(q, d, k) = \text{xelc}(q, d, \text{EL}) \\ \quad - \sigma_{\text{ln}}(q, d) [\text{pln}(q, d, k) - \text{pelc}(q, d, \text{EL})], k \in \{\text{LNI}, \text{LNUW}, \text{LND}\} \end{array} \quad (4)$$

and

$$\text{pelc}(q, d, \text{EL}) = \sum_k \text{SLN}(q, d, k) * \text{pln}(q, d, k) \quad (5)$$

where

$\text{xln}(q,d,k)$ ,  $\text{xelc}(q,d,\text{EL})$ ,  $\text{pln}(q,d,k)$  and  $\text{pelc}(q,d,\text{EL})$  are percentage changes in the variables defined by the corresponding uppercase symbols;

---

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

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

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

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

#### *Demands for effective land and cereal*

In deciding its inputs of effective land (EL) and cereal (C) we assume that farm industry  $(q,d)$

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

subject to

$$XTLOP(q,d,TL) = CES_k(XELC(q,d,k) / AELC(q,d,k)) \quad (8)$$

where

$XELC(q,d,k)$  refers to inputs to industry  $(q,d)$  of  $k$  (effective land or cereal);

$PELC(q,d,k)$  is the cost to industry  $(q,d)$  of using a unit of input  $k$  (effective land or cereal)<sup>2</sup>;

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

$AELC(q,d,k)$  are variables that can be used to introduce productivity changes. For example, if  $AELC(q,d,EL)$  increases by 50 per cent, then for any given input of cereal, industry  $(q,d)$  needs 50 per cent more effective land to achieve any given level of total land requirements. Equivalently, if  $AELC(q,d,EL)$  increases and effective land input is held constant, then industry  $(q,d)$  will need to increase its input of cereal to achieve a given level of total land input.  $AELC(q,d,EL)$  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:

$$\begin{aligned} &xelc(q,d,k) - aelc(q,d,k) = xtlop(q,d) \\ &\quad - \sigma_{tln}(q,d) \left[ pelc(q,d,k) - \sum_j SELC(q,d,j) * pelc(q,d,j) \right] \\ &\quad - \sigma_{tln}(q,d) \left[ aelc(q,d,k) - \sum_j SELC(q,d,j) * aelc(q,d,j) \right], \quad k \in \{EL, C\} \end{aligned} \quad (9)$$

where

<sup>2</sup>  $PELC(q,d,EL)$  is defined by (3).  $PELC(q,d,C)$  can be defined in a standard way in terms of prices of cereal from different regions via the CES specification in the bottom right hand corner of Figure 2.

$xelc(q,d,k)$ ,  $pelc(q,d,k)$ ,  $aelc(q,d,k)$  are percentage changes in the variables defined by the corresponding uppercase symbols;

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

$SELC(q,d,j)$  is the share of  $j$  (effective land and cereal) in  $(q,d)$ 's cost of total land, that is:

$$SELC(q,d,j) = \frac{PELC(q,d,j) * XELC(q,d,j)}{\sum_k PELC(q,d,k) * XELC(q,d,k)}, j \in \{EL, C\}. \quad (10)$$

#### *Demands for operator labour and total land*

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

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

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

where

$XTLOP(q,d,k)$  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  $k^3$ ;

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

The percentage-change equations arising from (11) and (12) that are included in TERM-H2O are:

$$\begin{aligned} xtlop(q,d,k) = xlokh(q,d,LO) - \sigma(q,d) \left[ ptlop(q,d,k) - \sum_j S(q,d,j) * ptlop(q,d,j) \right], \\ k \in \{TL, OP\} \end{aligned} \quad (13)$$

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:

<sup>3</sup> Movements in  $PTLOP(q,d,OP)$  are determined by movements in the demand for and supply of owner operators. Percentage movements in  $PTLOP(q,d,TL)$  are determined according to:  
 $ptlop(q,d,TL) = \sum_k SELC(q,d,k) * (pelc(q,d,k) + aelc(q,d,k))$ .

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

*Demand for irrigation water and irrigable land in formation of irrigated land*

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

$$PLN(q, d, LNI) = PLN(q, d, LNUW) + WPH(q, d) * PW(d), \quad (15)$$

where

PW(d) is the price or value per unit of irrigation water in region d; and

WPH(q,d) 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.

In (15) we assume that irrigation water is freely movable between irrigation industries in region d implying that it has the same price throughout a region.

The percentage change form of (15) for inclusion in TERM-H2O can be written as:

$$pln(q, d, LNI) = SLNUW(q, d) * pln(q, d, LNUW) + SW(q, d) * pw(d), \quad (16)$$

where

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

SW(q,d) is the share of irrigation water in the cost to (q,d) of using irrigated land; and

SLNUW(q,d) is the share of rents on irrigable land (before application of water) in the cost to (q,d) of using irrigated land.

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

(iii) *Calibrating input-demand equations in TERM-H2O*

To implement equations (4), (5), (9), (13) and (16) in TERM-H2O, we need to specify initial values for share coefficients and values for substitution parameters. The initial values for the share coefficients are computed from the input-output database represented by Figure 1. For dry-land industries,  $SLN(q,d,k)$  used in (5) is computed from the dry-land and unwatered-irrigable-land rows of Figure 1. For irrigated industries,  $SLN(q,d,k)$  is one for  $k = LNI$  and zero otherwise. For dry-land industries,  $SELC(q,d,j)$  used in (9) is computed from the sum of the entries in  $(q,d)$ 's cereal rows and the sum of the entries in its two land rows. For irrigated industries  $SELC(q,d,j)$  is one for  $j = EL$  and zero for  $j = C$ . For all industries,  $S(q,d,j)$  used in (13) is computed from the operator-labour row and the sum of the cereal, two land and irrigation-water rows. For irrigated industries,  $SW(q,d)$  and  $SLUW(q,d)$  in (16) are computed from the irrigation-water and unwatered-irrigable-land rows of Figure 1. For dry-land industries these two coefficients are irrelevant.

For  $\sigma_{ln}(q,d)$ , the elasticity of substitution between land types 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 unwatered.

For  $\sigma_{tln}(q,d)$ , the elasticity of substitution between effective land and cereal appearing in (9), we adopted a value of 3. This elasticity is relevant only for dry-land livestock industries. The parameter is large enough to induce substantial substitution away from irrigated livestock production when water scarcity worsens relative to other inputs (see appendix).

For  $\sigma(q,d)$ , the elasticity of substitution between total land and operator labour appearing in (13), we adopted the low value of 0.5, implying that total land and operator labour usually move closely together. 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,  $XELC(q,d,EL)$ , and hectares of land input is not as tight as for irrigation industries. Nevertheless, with high substitution between unwatered irrigable land and dry land [high values for  $\sigma_{ln}(q,d)$ ] we can think of  $XELC(q,d,EL)$  as being the number of hectares of land used.<sup>4</sup> For dry non-livestock industries, total land is approximately  $XELC(q,d,EL)/AELC(q,d,EL)$ . 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.

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<sup>4</sup> More accurately, the high value of  $\sigma_{ln}(q,d)$  means that  $XELC(q,d,EL)$  is approximately a linear combination of  $XLN(q,d,LNUW)$  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.

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 cereal 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 cereal.

#### *IV Region-wide constraints and the determination of factor rents and prices for water*

In this section we discuss the region-wide constraints applying to operator labour, irrigable land, dry land and physical capital. We also discuss the rental prices of these factors and the price of irrigation water.

##### *(i) Determination of rents*

We assume that each region  $d$  has available for year  $t$  fixed amounts of the factors irrigable land (LNIRR)<sup>5</sup>, dry land (LND), operator labour (OP) and agricultural capital (K), that is there is a fixed amount of each  $f$  in the set  $\{LNIRR, LND, OP, K\}$ . For each  $f$ , TERM-H2O allocates this fixed amount between the  $H(d)$  farm industries in region  $d$  in a price sensitive way according to the optimization problem

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

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

where

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

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

$PZ(q,d,f)$  is the rental rate for factor  $f$  when used by industry  $(q,d)$ . In section III,  $PZ(q,d,LNIRR)$ ,  $PZ(q,d,LND)$  and  $PZ(q,d,OP)$  were denoted as  $PLN(q,d,LNUW)$ ,  $PLN(q,d,LND)$  and  $PTLOP(q,d,OP)$ .

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

$$z(q, d, f) = ztot(d, f) + \tau(d, f) * (pz(q, d, f) - \sum_v R(v, d, f) * pz(v, d, f)) \quad ,$$

for all  $(q,d)$  and  $f$ , (19)

where

$z(q,d,f)$ ,  $ztot(q,d,f)$  and  $pz(q,d,f)$  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

---

<sup>5</sup> Irrigable land can be used as irrigated land (LNI) or as unwatered irrigable land (LNUW).

$\tau(d,f)$  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 III, and with supplies specified through the optimization problems set out in this section, TERM-H2O determines rental rates via market-clearing equations:

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

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

$$XLN(q,d,LNI) = Z(q,d,LNIRR) \quad , \text{ for irrigated industries } q \text{ and regions } d \quad (22a)$$

$$XLN(q,d,LNUW) = Z(q,d,LNIRR) \quad , \text{ for dry industries } q \text{ and regions } d \quad (22b)$$

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

(ii) *Determination of the price of irrigation water*

The supply of irrigation water [ $ZW(q,d)$ ] to irrigation industry  $q$  in region  $d$  is given by:

$$ZW(q,d) = AW(q,d) + TRADE(q,d) + NatW(d) * XLN(q,d,LNI) \quad (24)$$

where

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

$NatW(q,d)$  is the amount of irrigation water per hectare supplied to  $(q,d)$  through rainfall;

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

$XLN(q,d,LNI)$  is, as defined earlier, the amount of irrigated land used by  $(q,d)$ .

The demand for irrigation water [ $XW(q,d)$ ] by irrigation industry  $(q,d)$  is given by:

$$XW(q,d) = WPH(q,d) * XLN(q,d,LNI) \quad . \quad (25)$$

$TRADE(q,d)$  is determined by equating demand and supply:

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

If no interregional water trade were allowed, then regional water prices [ $PW(d)$ ] could be determined by imposing the constraint that the sum over  $q$  of  $TRADE(q,d)$  is zero. However, TERM-H2O allows flexibly for different water trading regimes by including equations of the form:

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

and

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

where

$TRADE(d)$  is the net acquisition of water by region  $d$  through trade, that is

$$\text{TRADE}(d) = \sum_q \text{TRADE}(q, d) \quad ; \quad (29)$$

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

$\text{PWG}(g)$  is the price of irrigation water in trading group  $g$ ; and

$\text{Dummy}(d,g) = 1$  if  $d$  is in trading group  $g$  and zero otherwise.

Then the no-interregional-trade case is handled by making  $G$  the number of regions so that (27) and (28) reduce to:

$$\text{PW}(d) = \text{PWG}(d) \text{ for all } d \quad (30)$$

and

$$\text{TRADE}(d) = 0 \text{ for all } d . \quad (31)$$

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

$$\text{PW}(d) = \text{PWG}(1) \text{ for all } d \quad (32)$$

and

$$\sum_d \text{TRADE}(d) = 0 . \quad (33)$$

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:

$$\text{PW}(d) = \text{PWG}(1) \text{ for all } d=1, \dots, R_1 \text{ and } \text{PW}(d) = \text{PWG}(2) \text{ for all } d= R_1+1, \dots, R \quad (34)$$

and

$$\sum_{d=1}^{R_1} \text{TRADE}(d) = 0 \text{ and } \sum_{d=R_1+1}^R \text{TRADE}(d) = 0 . \quad (35)$$

### *V Database amendments*

Preparation of a suitably disaggregated multi-regional database entailed a number of steps summarized in Figure 3. The published IO table released by ABS distinguishes 109 sectors. Some of the main irrigation crops, namely grapes, cotton, fruit and vegetables are represented by a single composite sector (other agriculture) in the published table. Our model requires separate representation of different irrigation activities with differing water requirements. Therefore, the first step in regional database preparation procedure was to split the national database to sectors of interest. In agriculture, we relied on unpublished ABS agricultural data (AgStats) to split the national data. Our enlarged national IO database included 172 sectors.

The next step was to choose a suitable base year. We chose to update the IO table to 2005-06.<sup>6</sup> This enabled us to align the national database with the 2006 census, from which we obtained small-region data at the three-digit ANZSIC level for services and at the four-

<sup>6</sup> URL: [www.monash.edu.au/policy/archivep.htm](http://www.monash.edu.au/policy/archivep.htm) TPMH0058 contains the program used in this procedure.

digit level for other sectors. ABS census data includes employment by industry for each of 1400+ statistical local areas. These census data together with AgStats data supplement ABS IO data for agriculture by representing grapes, fruit trees, rice and cotton as individual sectors, thereby allowing us to enhance versions of TERM dealing with irrigation sectors and water accounts.

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 the 172 sectoral level. The motivation for this level of detail is that it allows us to cover many of the major 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.

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 farm sectors (10 out of 28) 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). After further database modifications as outlined below, we aggregate TERM to 19 regions shown in Figure 4 to reduce solution time and ease presentation of results.

With the 28 sector, 46 region database, the next step is to split farm sectors into irrigation and dry-land sectors. ABS (2009) provides both the value of irrigation production and volume of water used for various crops and livestock in the Murray-Darling basin. It also provides total output values (dry-land plus irrigation) for these sectors. These data are the main basis for the dry-land—irrigation split. 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. In addition, ABS (2008) provides total water usage by statistical division. These data together with farm employment data from the 2006 census are sufficient to estimate small region irrigation and dry-land agricultural activity by sector. For example, the Murray statistical division's actual water use was higher than estimated by our initial split based on the split between irrigated and dry-land production by sector provided by the ABS for the whole basin. The irrigated share of non-dairy livestock production (a large farm sector in the region) was adjusted upwards in Murray so that it was higher than for the total basin. This enabled us to match the published water usage for the region. Following this step, we have 35 industries producing 28 commodities.

Finally, we had to account for the value of water in production in the database. The year on which we base TERM-H2O (2005-06) was the most recent of the years with available data in which water was relatively abundant. Given this, in the TERM-H2O 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. 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 unwatered irrigable land. A negligible value is assigned to dry-land rentals. Given the unit cost of water imposed above, the shares of irrigation water in primary factor costs (the cost of water plus returns to labour capital and land) are around 20% in the non-rice cereals, grapes, vegetables, fruit and other agriculture sectors, 10% in the irrigated cotton sector and around 50% in the rice sector.

FIGURE 3  
*Data generation procedure for TERM-H2O*

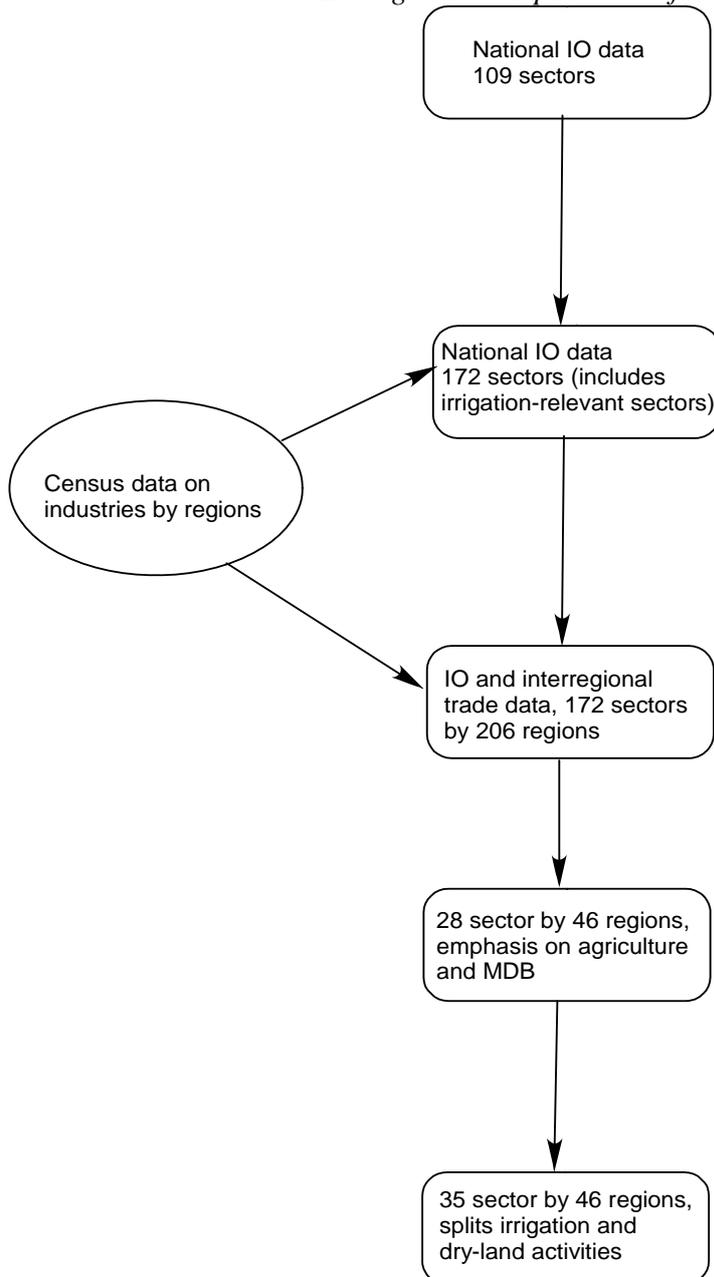
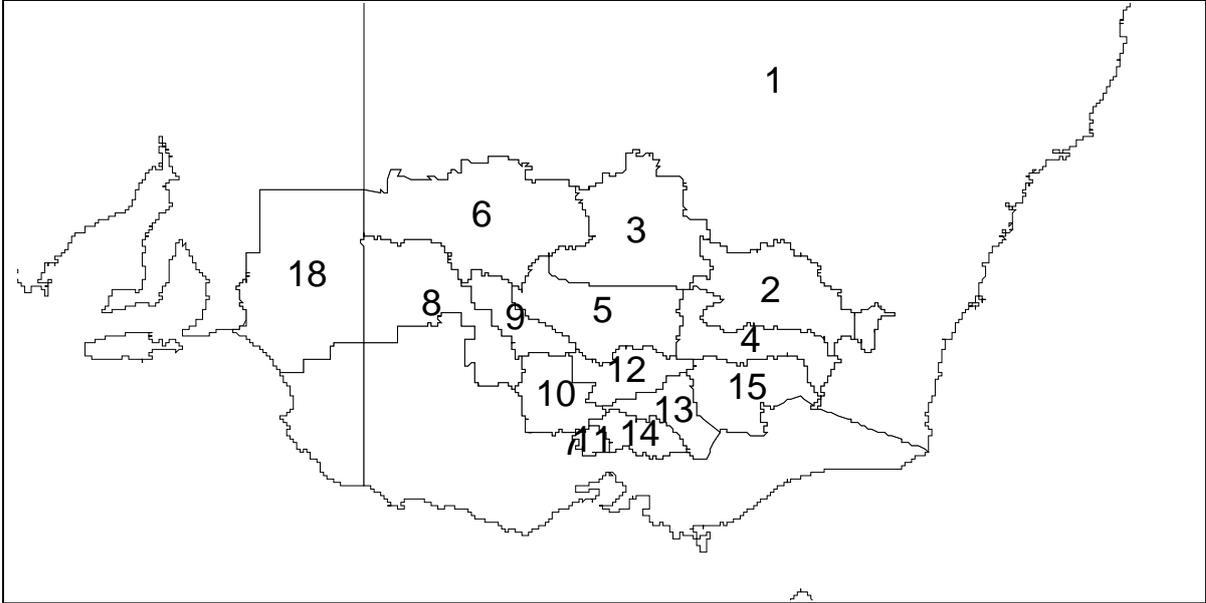


FIGURE 4  
*Regions in this application of TERM-H2O*



*Regions:*

1 RofNSW, 2 WagCntMrmNSW, 3 LMrbNSW, 4 AlbUpMrryNSW,  
 5 CentMrryNSW, 6 MrryDrIngNSW, 7 RoVIC, 8 MidWMaleeVic, 9 EMalleeVic,  
 10 BndNthLodVic, 11 SthLoddonVic, 12 ShepNGoulVic, 13 SGoulburVic, 14 SWGoulbuVic, 15  
 OvensMurVic, 16 QLD, 17 RoSA, 18 MurrayLndsSA, 19 RoA.

*VI Additional features: the impacts of water trading and constraining trade*

*(i) Irrigation water price equalisation*

In typical applications of TERM-H2O, we start with a database in which the price of irrigation water is equal across all irrigators in all regions. In the usual closure, we permit trading across the entire SMDB and also permit trade between users in other individual regions. But there may some simulations in which we wish to move from a year in which trade between regions or users was not permitted to a year in which it is. We may wish to estimate the impact of water trading in isolation. The following solves for the price of water in the SMDB:

$$0.01 * PW(q,d) * pw(q,d) = -PW0(q,d) * delUnity + delwatall \quad (36)$$

In the above,  $PW0(q,d)$  is the initial water price for each irrigation sector in all regions of the SMDB. With  $delwatall$  endogenous, a homotopy shock (denoted by a shock of 1 to  $delUnity$ ) results in  $pw(q,d)$  adjusting in each sector so that the updated level  $PW(q,d)$  is equal for all users at a value that clears the regional market for irrigation water.

*(ii) Constraining the volume of water traded*

The theory of TERM-H2O allows for the price of water to be equalized in either a single region or a group of regions through water trading. It is possible there are engineering or institutional constraints to water trading that prevent a sufficient volume of water moving

between regions to equalize prices. To make allowance for a water trading constraint, we have added a complementarity condition to TERM-H2O. Harrison *et al.* (2004) describe the implementation of complementarities within GEMPACK software.

A complementarity allows one of two conditions: either the volume of water traded is below the physical or institutional 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 irrigators is equalized within a feasible water trading region. In the latter case, the binding constraint prevents more than a certain volume of water from being exported from a region. The marginal product of water within that region will remain below that of other regions within the trading zone.

The constraint takes the form:

$$\frac{-\sum_q \text{TRADE}(q, d)}{\sum_q \text{ZW}(q, d)} \leq \text{TRD\_WAT\_PER}(d)$$

where  $\text{TRD\_WAT\_PER}(d)$  is the maximum permitted volume of water traded out of a region.

In adding the complementarity condition into the model, we need to amend equation (36) as follows:

$$[0.01 * \text{PW}(q, d) * T(d)] * (\text{pw}(q, d) + t(d)) = -[\text{PW0}(q, d) * T0(d)] * \text{delUnity} + \text{delwatall} \quad (37)$$

In (36),  $T0$  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  $t(d)$ . When it is not binding,  $t(d)$  is unchanged and all the adjustment in the water price is via  $\text{pw}(q, d)$ .

## VII 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 SMDB 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. 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 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). Target macro variables including regional real GDP, aggregate employment, aggregate consumption, aggregate investment and export volumes are usually endogenous. We make them exogenous through swaps 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 to avoid linearization errors. 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. This enables us to include forecasts over time, while running the model with a closure that is similar to that of comparative static analysis. 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 in the early years. 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 and the welfare losses from buyback smaller. Table 4 in Section VIII shows how altering assumptions concerning drought affects the simulation results.

### *VIII The core scenario*

In our scenario, the Commonwealth makes incremental purchases of permanent water rights each year for eight years from irrigators in the SMDB. Each increment is 187.5 gegalitres (GL) so that after eight years, Commonwealth purchases total 1500 gegalitres. Each year, purchases from holders of water rights are made in proportion to the volume of each right. We allow full water-trading across the SMDB: that is, water is traded year-by-year until prices to all irrigators equalise across the region. 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.

*(i) Theoretical modifications to deal with the buyback plan*

Two 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 incremental 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 annualized value of buyback purchases to original holders of water rights each year.

*(ii) The forecast baseline*

The baseline includes the usual assumptions of dynamic baselines, including technological change and underlying macro forecasts. In the baseline, real GDP nationally grows by an average of 4.3 percent annually and real consumption by an average of 3.6 percent annually between 2009 and 2018. The results we present are as deviations from forecast.

The scenario consists of permanent water rights amounting to 1500 GL being purchased by the Commonwealth incrementally over an 8 year period. That is, the Commonwealth purchases 187.5 GL of permanent rights in the first year followed by 187.5 GL in the second year, and so on, until purchases amount to 1500 GL. Since 1500 GL extracted from the SMDB over time represents a substantial share of water used in the region (around 25.8 percent inclusive of natural rainfall), the policy will have a significant impact on irrigation water prices. 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 net present value (NPV) price will rise for permanent water rights. To reflect drought, baseline allocations in 2009, the first year of the policy simulation, are only 70 percent of full entitlements and remain so in 2010. There is a partial restoration of allocations in 2011 followed by a full restoration in 2012.

*(iii) Analysing the impacts*

We start by examining the contributions of dry-land and irrigation output to GDP at the regional level (Table 1). Across the entire SMDB, irrigation agriculture accounts for 6.5 percent of GDP and dry-land agriculture a further 6.0 percent. The most irrigation-intensive regions are Central Murray (21.8% of GDP), Lower Murrumbidgee (16.8% of GDP), East Mallee (15.9%), Murray Lands (14.7%) and Murray-Darling (13.8%).

TABLE 1:  
SECTORAL CONTRIBUTIONS TO GDP BY REGION, 2009 (%)

	dry-land ag	Irig ag	FoodDrinks	Other	Services	Total
WagCntMrmNSW	7.7	1.8	4.8	8.4	77.3	100
LMrmbNSW	7.7	16.8	15.6	4.7	55.2	100
AlbUpMrryNSW	5.6	1.1	3.9	14.9	74.5	100
CentMrryNSW	2.0	21.8	7.0	7.2	62.0	100
MrryDrlngNSW	6.8	13.8	8.0	7.1	64.3	100
MldWMaleeVic	12.1	8.6	9.3	6.1	64.0	100
EMalleeVic	12.8	15.9	5.2	5.7	60.4	100
BndNthLodVic	3.3	1.5	4.9	14.1	76.2	100
SthLoddonVic	1.2	0.8	3.2	12.5	82.3	100
ShepNGoulVic	6.2	9.9	9.8	8.5	65.6	100
SSWGlbrnVic	6.5	3.2	4.0	12.3	73.9	100
OvnsMurryVic	3.5	2.9	7.2	11.9	74.4	100
MurrayLndsSA	6.9	14.7	12.5	5.7	60.2	100
<b>SthMdb</b>	6.0	6.5	7.1	10.0	70.4	100
<b>National</b>	2.0	1.1	1.9	19.6	75.5	100

Sources: ABS national accounts; ABS census data; ABS catalogue 4610.0.55.008; TERM-H2O projections.

TABLE 2  
COMPARING BACK-OF-THE-ENVELOPE TO MODELLED OUTCOMES,  
2018 POLICY RELATIVE TO FORECAST

	<i>BoTE</i>		<i>Modelled outcomes</i>						
	(1) water <sup>a</sup>	(2) GDP	(3) xwat <sup>b</sup>	(4) xtot <sup>c</sup>	(5) apparent xwat- xtot <sup>d</sup>	(6) actual xwat- xtot <sup>e</sup>	(7) GDP%	(8) Water traded GL	(9) B/C <sup>f</sup>
WagCntMrmNSW	-23.2	-0.4	-54.6	-29.0	-36.0	-9.5	-0.07	105	0.23
LMrmbNSW	-28.8	-4.8	-29.9	-12.1	-20.3	-3.7	-0.76	13	2.26
AlbUpMrryNSW	-21.5	-0.2	-46.9	-24.2	-30.0	-11.4	-0.09	27	0.10
CentMrryNSW	-25.3	-5.5	-16.3	-6.7	-10.3	-0.2	-1.67	-123	3.64
MrryDrlngNSW	-26.4	-3.6	-13.4	-3.5	-10.3	-4.6	-0.56	-9	0.62
MldWMaleeVic	-23.5	-2.0	-28.5	-9.5	-21.0	-6.4	-0.37	21	0.81
EMalleeVic	-25.9	-4.1	-20.6	-6.2	-15.3	-5.6	-0.62	-20	0.87
BndNthLodVic	-21.8	-0.3	-35.7	-15.5	-23.9	-9.6	-0.1	24	0.09
SthLoddonVic	-22.8	-0.2	-21.2	-7.8	-14.5	-7.4	-0.06	0	0.02
ShepNGoulVic	-26.2	-2.6	-22.9	-8.7	-15.5	-7.3	-0.55	-31	0.76
SSWGlbrnVic	-23.2	-0.7	-33.1	-13.3	-22.9	-9.0	-0.18	23	0.21
OvnsMurryVic	-24.5	-0.7	-27.2	-12.4	-16.9	-9.8	-0.23	6	0.17
MurrayLndsSA	-28.2	-4.1	-19.4	-4.6	-15.5	-6.1	-0.42	-35	0.59
All Sth MDB	-25.8	-1.7	-25.8	-11.8	-15.9	-5.9	-0.33	0	0.54

Key: a Differences between regions arise from including rainfall plus irrigation water in the % change in water availability

b  $xwat_i = \sum_i [W_i \cdot xwat_i] / \sum_i W_i$  for irrigation sector i: W is the volume of water applied and xwat its % change.

c  $xtot_i = \sum_i [PRIM_i \cdot xtot_i] / \sum_i PRIM_i$  for irrigation sector i: PRIM is the value-added and xtot % change in output.

d  $xwat_i - xtot_i$  corrected for linearisation error.

e  $\sum_i [PRIM_i \cdot (xwat_i - xtot_i)] / \sum_i PRIM_i$ .

f Buyback revenues as % of aggregate consumption

Columns (1) and (2) in Table 2 include back-of-the-envelope (BoTE) calculations: the first is the direct impact of buyback on regional water availability, and the second the calculated direct impact of reduced water availability on regional GDP, equal to column (1) multiplied by the region's irrigation activity as a share of GDP (i.e., the 2<sup>nd</sup> column in Table 1). This is starting at a pessimistic point for estimating the impact on regions, for reasons that follow. The BoTE impact is -4.8 percent for Lower Murrumbidgee, -5.5 percent for Central Murray, -4.1 percent for East Mallee, -2.6 percent for Shepparton-North Goulburn and -4.1 percent for Murray Lands. For the entire SMDB, from which 1,500 GL of permanent water rights have been purchased by 2016, the BoTE impact on real GDP is -1.7 percent.

In summary, our BoTE calculation includes the following assumptions:

1. There is no water trading between users at all;
2. there are no long-term reductions in water requirements per unit of output induced by the greater scarcity of irrigation water;
3. all productive factors used in irrigation activity remain idle as water usage is reduced;
4. water is taken away from farmers without payment; and
5. there are no multiplier effects.

These assumptions are not consistent with the theory of TERM-H2O. Therefore, we expect the modelled outcome for real GDP by region to differ from the BoTE calculation. We can go through each of these assumptions to show how the model differs in its assumptions from above.

First, column (1) showing the aggregate reduction in water availability does not match (3), which shows the percentage change in each region in aggregate water used in irrigation ( $x_{wat\_i}$ ) in 2018 relative to forecast. This indicates that in the model, there is trading of water between regions, the net volumes of which are shown in (8). Second, there is mobility of farm factors within each region, so that if water availability falls, farmers can either move to different irrigation activities or to dry-land activities rather than allow factors to remain idle as water availability falls. TERM-H2O theory differs from the third BoTE assumption, because there are price-induced water savings per unit of output. Column (4) shows the percentage change in aggregate irrigation output ( $x_{tot\_i}$ ). Column (5) calculates the change in water requirements per unit of output as the percentage change in aggregate water minus aggregate irrigation output ( $x_{wat\_i} - x_{tot\_i}$ ). Across the SMDB, water usage in irrigation drops by 25.8 percent yet irrigation output drops by only 11.8 percent. This implies that average water requirements fall by 15.9 percent (Table 2, bottom row). In some regions, this apparent saving is larger: for example, in Wagga-Central Murrumbidgee, the fall in aggregate water used relative to aggregate irrigation output is 36 percent. Column (5) is an aggregate measure of water savings that does not take account of compositional change that arises from factor mobility. To obtain average water savings by region while taking account of such compositional change, we calculate individual industry changes in water requirements ( $x_{wat}$ ) minus individual changes in output ( $x_{tot}$ ) and then to aggregate using share-value weights (see Table 2, footnote e), as in column (6). Now, the average reduction relative to forecast in 2018 in water requirement per unit of irrigation output is 5.0 percent for all the SMDB, while in Wagga-Central Murrumbidgee, the average fall shown is 9.5 percent. The differences between columns (5) and (6) arise because farm factors move to different outputs as water availability changes. Resource movements diminish the negative impact of removing water from production.

Farmers are paid for buyback water. Buyback revenues and net revenues from water sales in a given region raise the ratio of aggregate consumption to GDP. This is because water sales, although not contributing to a region's production do contribute to a region's income. Column (9) of Table 2 shows buyback revenues as a percentage of aggregate consumption in 2018. Across SMD, buyback revenues (calculated as an annualized flow on the sale of permanent rights) account for 0.54 percent of aggregate consumption in 2018. The highest contribution is in Central Murray (3.64 percent). Our assumption is that buyback revenues stay in the region of origin. Farmers could use buyback proceeds to restructure their farm or to retire. Column (9) indicates that buyback revenues are a relatively small proportion of aggregate consumption in each region.

Finally, the BoTE calculation does not include multiplier impacts. The assumption that multipliers could worsen direct impacts would be defensible if there were no payments to farmers for buyback water. Since buyback will entail such payments, there is the possibility of positive multipliers that will at least partly offset the negative impacts on irrigation production.

As a consequence of the theory of TERM-H2O differing from the assumptions underlying the BoTE calculation of GDP losses, the modelled GDP losses are only a fraction of BoTE losses as calculated above (Table 1). For all the southern MDB, the real GDP change is -0.33 percent, compared with a BoTE calculation of -1.7 percent. The Central Murray, in which irrigation agriculture accounts for the largest share of regional GDP in the southern MDB, has the largest loss in real GDP, -1.7 percent compared with a BoTE calculation of -5.5 percent (Table 1).

Figures 6 and 7 show the deviation from forecast of real GDP year-by-year. The kink apparent in most regions at year 2012 arises from the full restoration of water availability. Between 2009 and 2012, the baseline includes water allocations that are below 100 percent due to drought. This also applies to buyback volumes. With restoration of full allocations, the volume of water taken out of the economy increases relative to the case in which there are less than 100 percent allocations at the same time as the water price rises more sharply relative to forecast than in previous years (that is, buyback has an upward impact on policy prices up while recovery from drought has downward impact on forecast and policy prices). Together, the price and quantity impacts move real GDPs further from forecast in 2012.

Next, we examine the impact on regional real consumption (Figures 8 and 9). Buyback revenues accrue to the regions, increasing the ratio of consumption to GDP, as discussed already. The larger the value-share of water in regional GDP, the larger the positive impact of buyback on a region's spending power. Overall, Central Murray experiences the largest gains, around 1.0 percent above forecast by 2018 (Figure 8). Central Murray does best because the value of water as a share of GDP is the largest of any region in the initial database.

Employment impacts are also small. South Loddon has the largest percentage loss in employment of any region by 2018, amounting to around 0.2 percent (Figure 9). The initial adverse employment impact on Central Murray arises from the direct impact on irrigation sectors. Central Murray's irrigation sectors account for a larger share of GDP than in other regions, and its dry-land sectors for a relatively small share (Table 1). This makes farm factor mobility smaller than in other regions in response to reduced water availability so that

initially, the region loses employment. Eventually, the spending effect of Central Murray's buyback revenues leads to an increase in the output of the region's services sector relative to forecast, and in turn a recovery in employment.

FIGURE 5  
*Real GDP, Victorian MDB regions,  
 deviation relative to forecast baseline (%)*

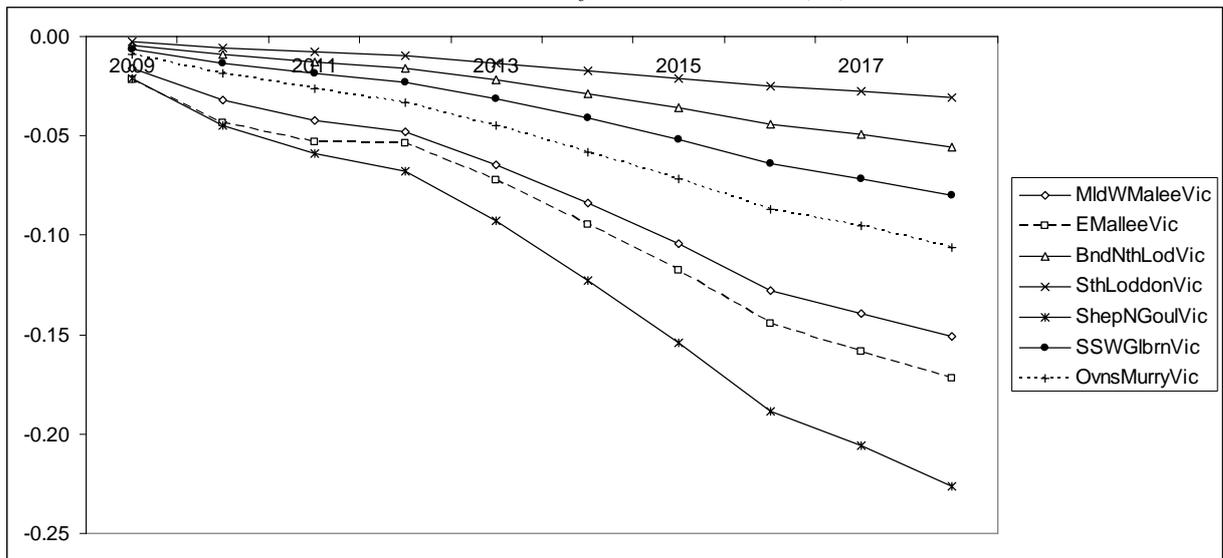


FIGURE 6  
*Real GDP, Other MDB regions,  
 deviation relative to forecast baseline (%)*

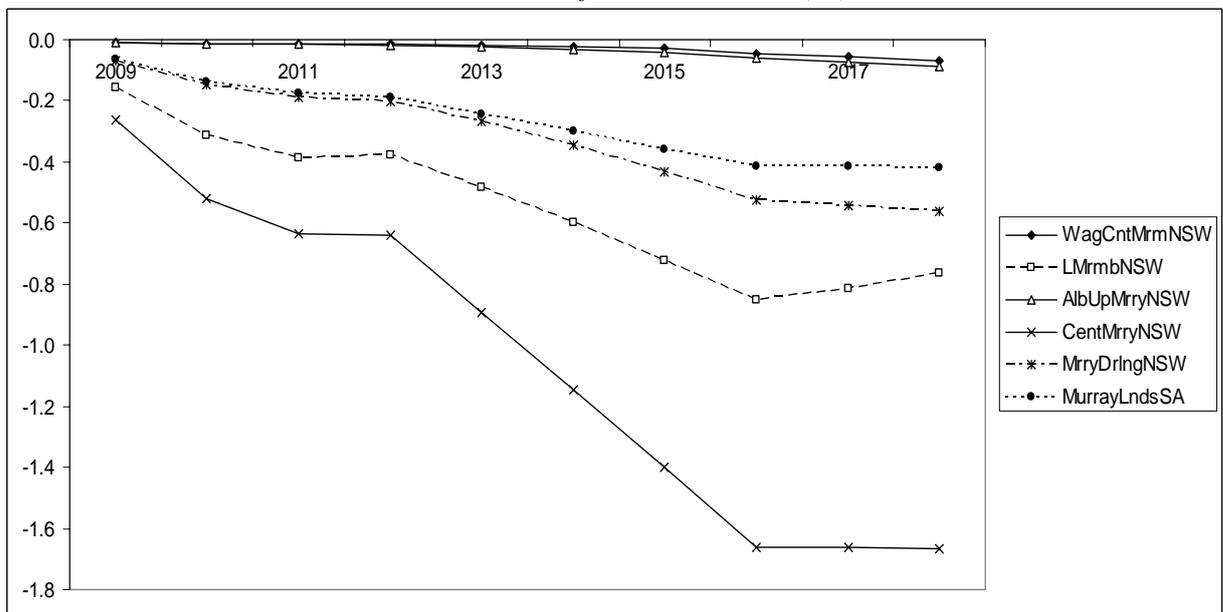


FIGURE 7  
*Real consumption, Victorian MDB regions,  
 deviation relative to forecast baseline (%)*

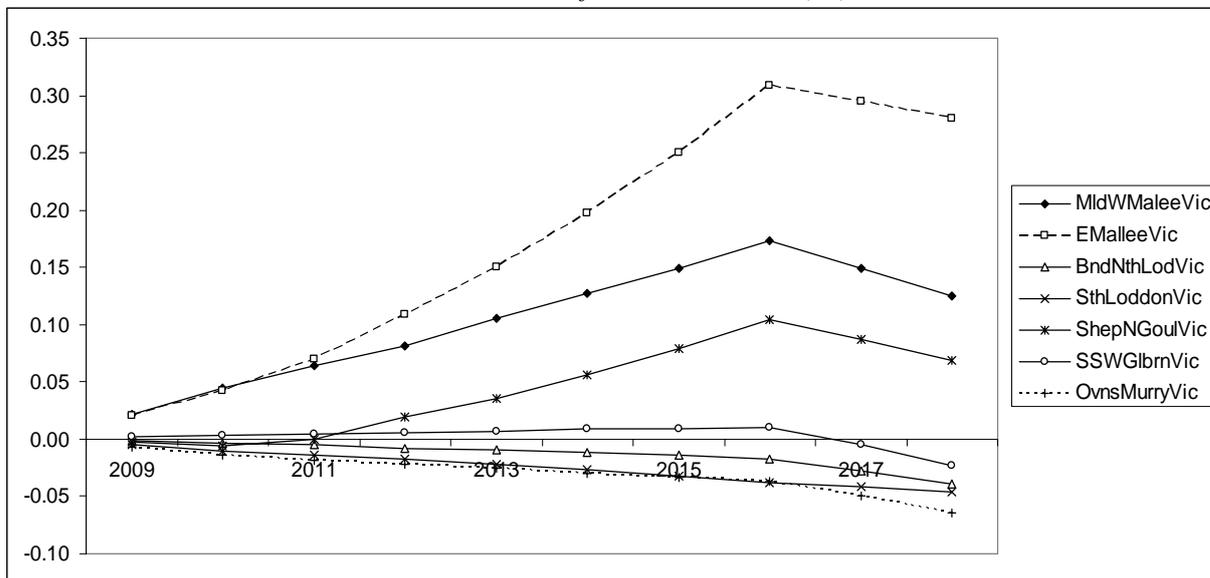


FIGURE 8  
*Real consumption, Other MDB regions,  
 deviation relative to forecast baseline (%)*

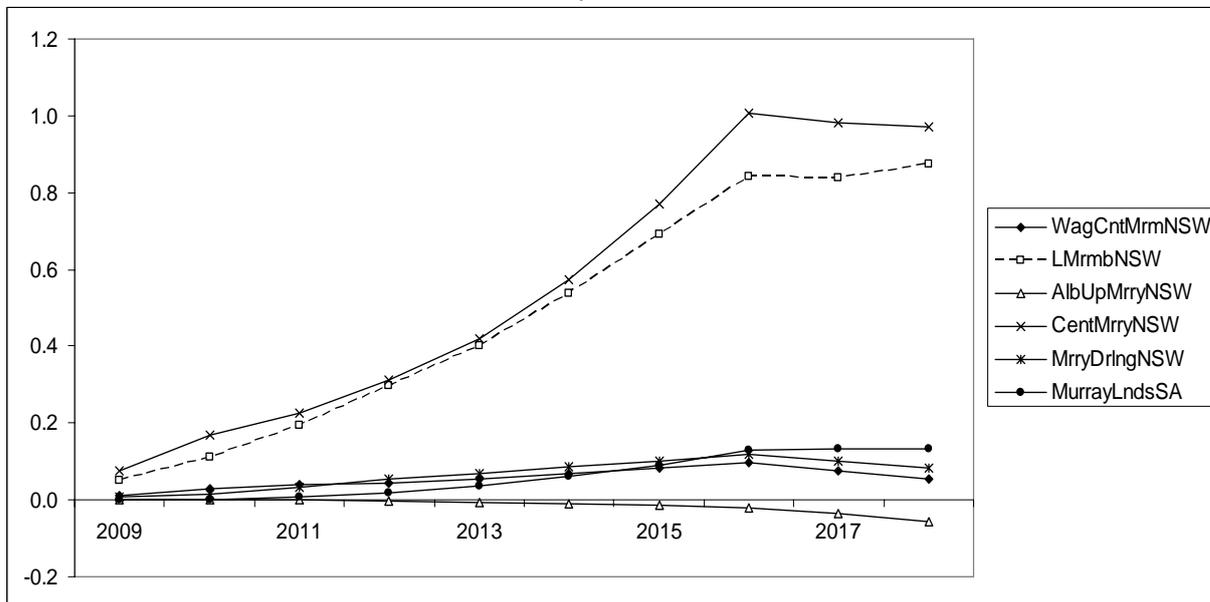


FIGURE 9  
*Employment, Victorian MDB regions,  
 deviation relative to forecast baseline (%)*

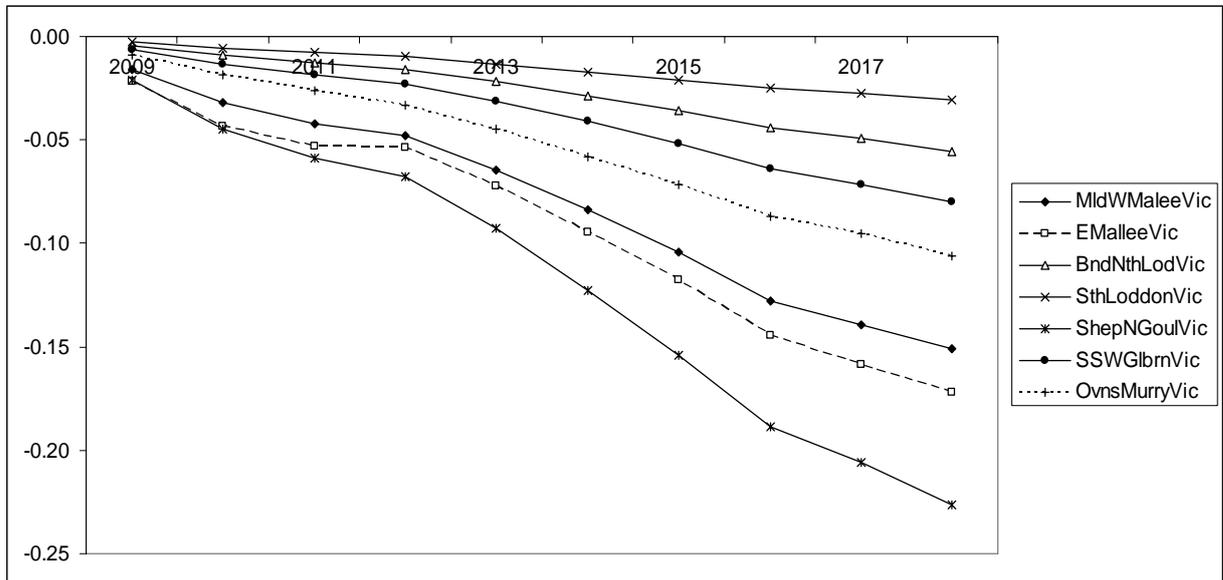
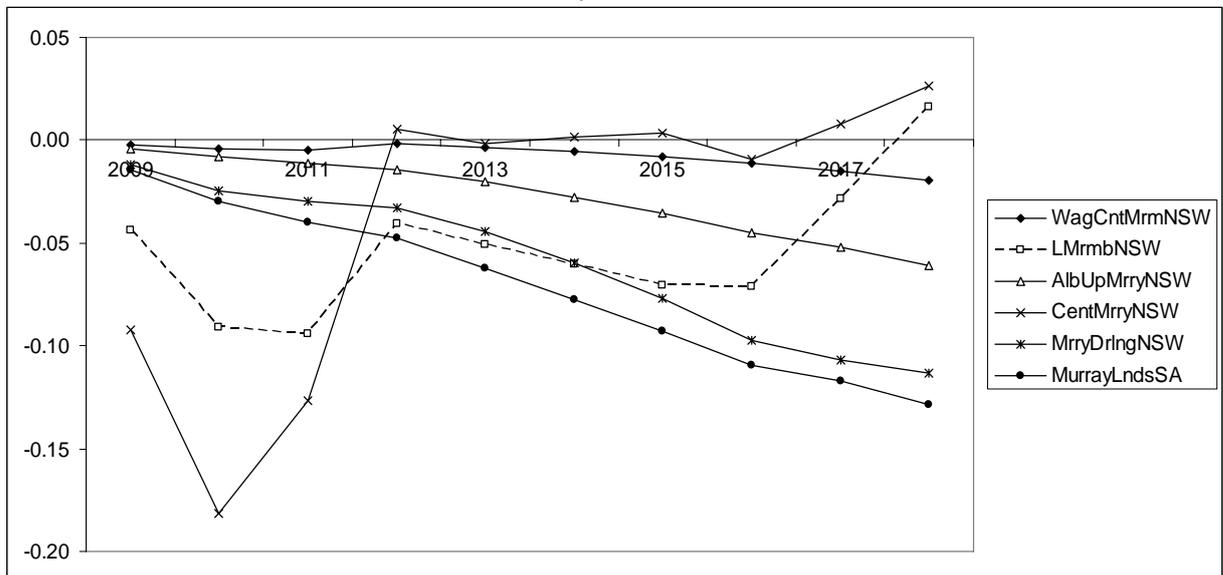


FIGURE 10  
*Employment, Other MDB regions,  
 deviation relative to forecast baseline (%)*



(iv) *National welfare*

To simplify our analysis of welfare impacts in this application of TERM-H2O, aggregate real national investment, real government consumption inclusive of buyback expenditures and the trade balance are exogenous. Since the deviation in aggregate national consumption is the only variable part of expenditure-side real GDP, it is a valid measure of

welfare. Figure 11 illustrates the national impact of buyback purchases. For a given demand for irrigation water ( $D_w$ ), buyback purchases reduce available water from  $V_0$  to  $V_1$  while increasing the price of water from  $P_0$  to  $P_1$ . The income loss arising from buyback will be equal to areas A+B, while the cost of buyback in a given year to the Commonwealth will be A+B+C.

FIGURE 11  
THE IMPACT OF BUYBACK ON NATIONAL GDP

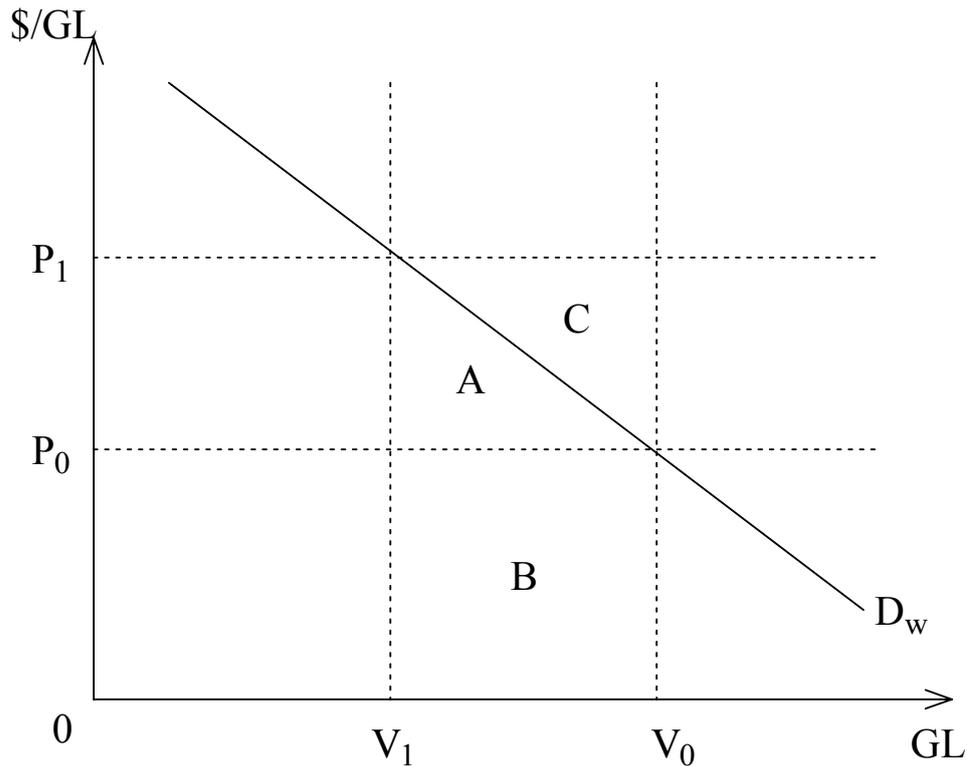


Table 3 compares back-of-the-envelope (BoTE) calculations based on Figure 11 and the modelled GDP losses arising from buyback, using policy ( $P_1$ ) and baseline ( $P_0$ ) water prices (i.e., year-by-year water prices from the policy and baseline simulations). In Table 3, the average of the baseline and policy water prices in row (3) multiplied by the buyback volume ( $V_1-V_0$ ) in row (1) provides a BoTE GDP result in millions of dollars (5) and as a percentage of GDP (6). This matches modelled GDP closely as shown in (7).

TABLE 3  
NATIONAL BOTE AND MODELLED OUTCOMES,  
RELATIVE TO FORECAST

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
(1) Buyback volume GL ( $V_1-V_0$ )	187.5	375	562.5	750	937.5	1125	1312.5	1500	1500	1500
(2) Price \$m/GL ( $P_1$ )	0.088	0.101	0.096	0.086	0.101	0.117	0.133	0.146	0.147	0.152
(3) Avg price \$m/GL ( $[P_1+P_0]/2$ )	0.085	0.094	0.085	0.069	0.076	0.084	0.090	0.094	0.092	0.092
(4) Cost to C'wealth \$m ( $A+B+C)=(1) \times (2)$ )	16.5	37.8	54.1	64.7	94.9	131.8	174.6	220.0	220.6	227.3
(5) GDP \$m ( $A+B)=(1) \times (3)$ )	-15.9	-35.1	-47.6	-51.4	-71.2	-93.7	-117.8	-141.2	-138.0	-138.3
(6) GDP % ( $A+B$ )	-0.0015	-0.0031	-0.0040	-0.0041	-0.0054	-0.0067	-0.0079	-0.0090	-0.0084	-0.0080
(7) % GDP (modelled)	-0.0015	-0.0030	-0.0038	-0.0038	-0.0049	-0.0060	-0.0071	-0.0084	-0.0081	-0.0077
(8) GDP deflator (2009=100)	100	102	105	107	109	113	116	118	122	125
(9) BoTE GDP (2009 dollars)	-16	-35	-46	-48	-65	-83	-102	-119	-114	-111
(10) Welfare modelled (\$m 2009)	-16	-35	-45	-48	-64	-82	-100	-123	-122	-122
(11) Discount deflator (5%)	1.00	1.05	1.10	1.16	1.22	1.28	1.34	1.41	1.48	1.55
(12) NPV contribution to buyback cost (\$m 2009)	16	35	47	52	71	91	112	132	122	117
(13) NPV contribution real GDP (\$m 2009)	-16	-33	-40	-41	-54	-65	-76	-85	-87	-71

The simulation as presented provides NPV contributions for the years from 2009 to 2018, as shown in Table 3: row (12) shows these contributions for buyback costs and row (13) for welfare costs. We have simulated an additional year in order to complete the NPV calculation. We can calculate NPVs using the following:

$$NPV = \sum_{Y_m} V_{Y_m} + V_{2019} / r \quad (38)$$

$V$  is the discounted annual real contribution to either buyback costs or GDP.  $Y_m$  covers the modelled years 2009 to 2018 (as shown in Table 3, rows (12) and (13)).  $V_{2019}$  is the real discounted value from 2019 and  $r$  the discount rate. Of relevance to the NPV calculations is the frequency of future droughts. To proceed with the NPV calculations, we run 2019 without a drought and then with a drought that results in 30 percent shortfalls in water allocations. We obtain water prices for the policy and baseline simulations in each case.

In Table 4, columns (1) and (2) show the buyback volumes, prices and the averages of the buyback and base prices for 2019 for drought and no drought respectively. In a drought with 30 percent shortfalls in water allocations, the volume of buyback water is only 1050 GL. Column (3) calculates the NPVs of buyback costs and welfare when there are zero droughts per decade, using only column (1) numbers. The NPV of buyback costs is \$3.04 billion and the welfare loss \$1.88 billion (2009 dollars). Column (4) repeats the calculations based on one drought per decade: it gives a weighting of 0.9 to column (1) prices and the buyback volumes and 0.1 to those in column (2). The NPV of buyback rises to \$3.16 billion and of the welfare loss to \$1.94 billion (2009 dollars). In column (5), representing three droughts per

decade, the weights are 0.7 from (1) and 0.3 from (2). The NPV of buyback costs rises to \$3.4 billion and of welfare losses to \$2.1 billion. Finally, for six droughts per decade, the NPV of buyback is \$3.8 billion and of welfare losses \$2.2 billion. These calculations would alter if we imposed additional years of drought on the core simulation from 2009 to 2018. In addition, in using a typical future year in the calculation, we assume that the real price of water is unchanged in future years. This implies that growing demands for water are offset by water-saving technologies.

TABLE 4  
NPVS OF BUYBACK UNDER DIFFERENT DROUGHT SCENARIOS<sup>a</sup>

No. of droughts per decade	no drought 2019 (1)	drought 2019 (2)	Zero (3)	One (4)	Two (5)	Six (6)
Available buyback volume GL	1500	1050	1500	1455	1365	1230
Buyback price \$m/GL	0.156	0.348	0.156	0.329	0.208	0.256
Avg (base+policy) water price \$m/GL	0.092	0.192	0.092	0.102	0.122	0.152
Cost to C'wealth \$m (annual)			235	248	274	313
GDP \$m (annual)			-138	-145	-157	-176
Discounted real cost <sup>d</sup>			112	118	131	150
Discounted real GDP			-66	-69	-75	-84
			Buyback NPV contributions (2009 dollars)			
		2019	2241	2366	2616	2991
		2009-2018	797	797	797	797
		Total	3039	3164	3414	3788
			Welfare NPV contributions (2009 dollars)			
		2019	-1322	-1383	-1503	-1684
		2009-2018	-559	-559	-559	-559
		Total	-1881	-1941	-2062	-2243

a The GDP deflator for 2019 is 129 (2009=100) and the discount rate 163 (2009=100).

(v) *Scenario variants: restricting water trade*

We ran the simulation again with no water trading between regions. The results barely change: the SMDB's real GDP by 2018 falls by 0.34 percent relative to forecast instead of 0.33 percent, with little impact at the national level. The small differences reflect little change in the average price paid by the Commonwealth for buyback water. That the results are similar for the full trading and no-trading case indicates that buyback has only a modest impact on the volume of inter-regional trades.

Finally, we ran the simulation with no inter-regional trading again, assuming this time that no buyback proceeds stay within the SMDB. Real GDP outcomes are marginally worse than in the main scenario: SMDB's real GDP now falls by 0.39 percent by 2018 relative to forecast, with Central Murray's real GDP falling 2.0 percent below forecast compared with 1.7 percent below in the main scenario (Figure 6). We expect this assumption to have the largest impact on Central Murray, as buyback revenues account for the largest share of aggregate consumption in the main scenario (Table 2, column (9)). The region's deviation in aggregate consumption from forecast in 2018 is -1.5 percent if no buyback proceeds are spent in the region, compared with a gain of 1.0 percent in the main scenario.

## *IX. Discussion*

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 5 and 6). 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.

During drought, the water purchased by the Commonwealth costs more and there is less of it. 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 high security 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. The current dire circumstances still warrant Commonwealth purchases, to the extent that environmental flows now are able to mitigate ecological damage in the SMDB.

The Council of Australian Government's plans for the Murray-Darling basin have a long way to go before the best environmental outcome is achieved for the money spent. The Victorian government's annual cap on permanent water trades out of catchment regions has hindered the process of buyback, as noted by the National Water Commission (2009). The reasons for the cap concern the possible adverse regional economic impacts of buyback and the issue of stranded assets. The modelling of this study debunks the concern that regions will suffer major economic losses, with such concerns possibly arising from a misapprehension that farmers would not be paid for buyback water, and exaggerated estimates of the contribution of irrigation to regional economies. On the issue of stranded assets, it is possible that the Victorian government's plans to upgrade irrigation infrastructure in northern Victoria, while providing some water efficiency gains, may worsen this problem in the long run. If water moves to more efficient activities, it is possible that it will move away from regions in which upgrades have taken place. The Victorian government's cap also has the potential to increase the costs of buyback to the Commonwealth substantially, by raising demand for permanent water from other regions by a larger proportion than if there were no restrictions in Victoria.

In turn, how the Commonwealth uses buyback water will also matter. Young and McColl (2008) propose a process to make optimal use of buyback water for the environment and economy. They suggest that when water is scarce during years of drought, buyback water should be sold to farmers. Then, in wet years, additional water should be purchased from farmers for environmental flows. As shown in Table 4, years of drought raise the value of buyback water. A given average annual volume of water could be set aside for the environment at lower cost by following this proposal.

At present, there are no plans for flexible environmental flows. Such plans would have the advantage of reducing the water allocation risk faced by farmers, particularly for perennials, while providing environmental flows at times when water is abundant. The

COAG (2008) agreement refers to the need to achieve environmental objectives “in the most efficient and effective way possible”, yet also states that environmental water “will only be traded in accordance with agreed principles” (p. 36). With current progress on policy formulation and enactment, such agreed principles may fall a long way short of providing an efficient outcome.

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 severe 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, agriculture’s share of GDP for all of Australia in the early 1960s (Maddock and McLean, 1987) was as high as the present share of agriculture in the SMDB’s GDP now (Table 1). The vitality of regional economies in the future will depend much less on preserving existing water volumes 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: Linking changes in water availability to observed usage*

A motivation for the extensive theoretical modifications in TERM-H2O is to track observed changes in water usage in response to changing water availability. Table A1 shows water usage by irrigation activity across the Murray-Darling basin. Livestock pasture, rice, cereals and cotton exhibited much wider variability in water use than grapes and fruit, vegetables or other agriculture in the period from 2001-02 to 2005-06.

Of particular interest is what happened from 2001-02 to 2002-03. Table A1 shows that water used dropped from 10,069 GL to 7,150 GL or 29 percent. In the same period, water usage in rice production fell by 69 percent, and by 21 percent in livestock pasture usage. Yet irrigated cereals usage increased by 21 percent. To explain why cereal usage rose, we need two additional details. First, dry-land production of cereals fell sharply in 2002-03 due to a national drought. Second, the cuts in water allocations at least in the southern part of the basin were concentrated in the Goulburn region, in which irrigation activities are dominated by dairy production.

TABLE A1  
*Water consumption, 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
<b>Total Agriculture</b>	<b>10,069</b>	<b>7,150</b>	<b>7,087</b>	<b>7,204</b>	<b>7,720</b>
Index (2001-02 = 100)					
Livestock pasture	100	79	86	80	87
Rice	100	31	41	31	63
Cereals (excl. rice)	100	121	86	83	77
Cotton	100	55	46	68	61
Grapes & fruit	100	106	100	105	107
Vegetables	100	94	128	100	100
Other agriculture	100	94	118	112	91
<b>Total Agriculture</b>	<b>100</b>	<b>71</b>	<b>70</b>	<b>72</b>	<b>77</b>

Source: ABS 4610.0.55.007, Table 4.20.

Irrigators appear to have responded to cereal prices, which rose due to the impact of drought on dry-land production, by switching to cereal production. Some of the water used in rice production the previous year appears to have moved to cereals. The theory of TERM-H2O allows rice producers to move factors into other irrigated crops in response to changing relative output prices. In addition, rice producers may have sold part of their annual allocation to other producers as the price of water rose with worsening scarcity.

Meanwhile, dairy producers in the Goulburn may have purchased some water to compensate for shortfalls in allocations. Their water shortages may also have led to a substantial switch to dry-land production, which in turn suffered from drought with a consequent substitution towards use of cereal inputs. The increased demands of Goulburn dairy producers may have contributed to rising cereal prices. This substitution possibility is included in TERM-H<sub>2</sub>O theory. An earlier version of TERM allowed such substitution, but did not have the same factor mobility in response to changing output prices and water availability (Wittwer 2003). This earlier version consequently was less responsive on the supply side and would not, for example, have been able to track the fall in water usage in rice production from 2001-02 to 2002-03.