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# Water charges and interregional trade
## in the southern Murray Darling Basin

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*This paper illustrates how irrigators' gains from interregional water trade in the southern Murray Darling Basin vary with the level and form of water delivery charges levied by regional water authorities. A simulation analysis is used to indicate the effect of different charging regimes on the systemwide and regional impacts of trade in the southern Murray Darling Basin.*

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# Introduction

An effective water market can be a mechanism for facilitating the transfer of water to higher value uses, thereby increasing the allocative efficiency of water use. Trade in temporary entitlements enables irrigators to manage risk that arises from variable seasonal conditions. Trade in permanent entitlements enables irrigators to mitigate the risks of sourcing increased environment flows from consumptive uses, and to invest in activities with large initial capital outlay such as horticulture. The value of trade is likely to increase over time as producers make new investments in higher valued activities and if more water is sourced from consumptive uses to meet environmental objectives.

While the volume of water traded has increased over recent years, trade in permanent water entitlements remains small — less than 1 per cent of diversions in 2001-02. Further, less than 1 per cent of the volume traded in both temporary and permanent entitlements was interregional — that is, between valleys or states (MDBC 2003).

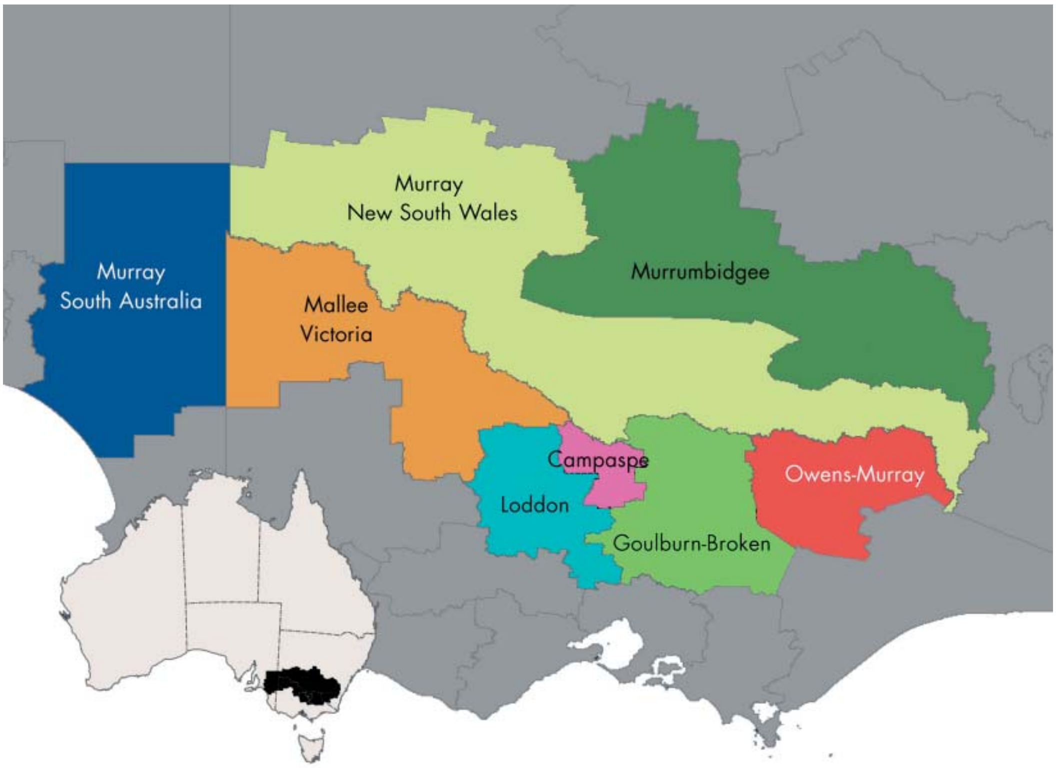
One reason for these low levels of interregional trade is the constraints imposed on trading water out of local valleys and interstate by irrigation authorities or corporations. An irrigation authority may want to retain water within a system to protect itself against the prospect of stranded assets — a situation where an irrigation authority is faced with large fixed infrastructure costs and a declining customer base. This situation may arise when an inappropriate charging regime is used to recoup the costs of delivering water. When customers leave an irrigation scheme, the fixed costs must be borne by the remaining water users. These higher charges may, in turn, lead to other irrigators trading their water out of the system. In this way, inappropriate charging regimes not only reduce the benefits from using water resources because they restrict the flow of water to higher value uses, they may even reverse the efficiency gains from trade (Goesch 2001).

The purpose in this paper is to illustrate how the gains to irrigators in the southern Murray Darling Basin from interregional water trade may vary with the level and form of water delivery charges levied by regional water authorities. The geographic area under consideration is shown in map 1. A simulation model was developed to highlight the impact of different delivery charge settings and to indicate how hypothetical, distorted delivery charge rules introduced when water is traded might affect the gains from water trade in the southern Murray Darling Basin.

# Water charging and the southern Murray Darling Basin

Gains from interregional trade in the southern Murray Darling Basin will be maximised where the marginal benefits from irrigation are equal to the marginal cost of delivering the water plus the traded price of water. Incentives for trade can arise from differences in returns to agricultural activities and the variable or volumetric delivery costs between

1 **Southern Murray Darling Basin**




regions. If demand for water is elastic, then changes in the delivery charge for water will result in larger volumes of water to be traded than when demand is relatively inelastic. Typically, demand for water in horticultural uses tends to be less elastic than that of broadacre crops, such as irrigated pasture. This is because of the large fixed capital investment in, for example, orchards and vineyards.

The structure of the charging regime, in terms of the way the supply authority recoups the costs of delivery, is important from an efficiency perspective. Given the large scale, capital intensive nature of water delivery systems, like most utilities, actual costs of operating and maintaining the system are largely fixed once the infrastructure is constructed. The combination of recurrent nonvolumetric or fixed costs, such as channel maintenance, and volumetric or variable delivery costs, means that average delivery costs are greater than marginal delivery costs at any volume of water use. Volumetric delivery costs may vary because of differences in the costs incurred. For example, water supplies delivered using a gravity feed will be less expensive to operate than a pumped or pressurised system. An appropriate charging regime ensures that the fixed costs of delivering water are distributed efficiently, while facilitating the transfer of water to higher value uses using a variable charge that reflects the true variable cost of delivery.

There are several options available to supply authorities to recoup the costs of delivering water for irrigation (see box 1). Given that an irrigation authority can act as a monopoly, it is possible for it to recover the full costs of delivery by combining its fixed and variable costs into a single charge known as average cost pricing. However, if delivery charges are set higher than marginal costs, as is the case in average cost pricing, this will result in too little irrigation as irrigators who cannot meet average costs but can meet marginal costs will choose not to irrigate. Further, if irrigation authorities seek to recoup delivery costs through average cost pricing, they will be exposed to the risk of stranded assets if trade is introduced where all charges are based on the volume of water delivered (Goesch 2001).

Ideally, the variable charge is set to equal the marginal cost of delivery, while the fixed fee is charged separately to cover the fixed or nonvolumetric costs of delivery. By maintaining the features of marginal cost pricing, a multipart tariff provides the opportunity to maximise the economic benefits from the use of delivery infrastructure while ensuring the long term viability of the supply authority through the use of the fixed fee. A two-part tariff with the capital costs of delivery directly contracted to irrigators significantly reduces the financial risk of stranded assets for water delivery authorities. The fixed fee can be collected as an annual charge through a long term contract or an exit fee.

Long term contracts could be introduced to finance new or refurbished infrastructure. The contract states the obligations of the licence holder and service provider. The service provider is obliged to maintain infrastructure, while irrigators are responsible for their share of fixed costs. Contracts internalise the costs incurred, provide long term revenue security to the provider and reduce the risks associated with additional infrastructure investment (Goesch 2001).

Exit fees are based on the net present value of future annual charges that the irrigator would have faced had they remained in the system. If irrigators are aware that they are liable for these costs, it will be considered in their production and water trade decisions. Provided that the variable cost reflects the marginal cost of delivery, the use of either exit fees or long term contracts will have little impact on efficiency.

Given the benefits of exit fees and long term contracts, long term contracts are advisable for new investments, and exit fees should be used to recoup remaining debts from irrigators as they leave the system. The advantage of a long term contract is the transparency it provides, as irrigators are aware of their capital liability prior to investment.

## Regional differences in water charges

There are six main irrigation water providers in New South Wales, and of these, three are located in the southern Murray–Darling Basin. Murrumbidgee Irrigation Limited, Coleambally Irrigation Co-operative Limited and Murray Irrigation source their bulk water supplies from New South Wales StateWater. StateWater is involved with the storage, ownership, operation and management of the state's major storages.

There are five main irrigation water providers in Victoria, each of which is a statutory authority with sole responsibility to deliver water to its customers holding water entitlements. Goulburn–Murray Water accounts for 90 per cent of all entitlements used for irrigation (NCC 2003). Goulburn–Murray Water is divided into the Shepparton, Central Goulburn, Rochester–Campaspe, Pyramid–Boort, Murray Valley and Torrumbarry irrigation districts.

Most irrigation in South Australia is managed by the three irrigation trusts — Central Irrigation Trust, Renmark Irrigation Trust and Sunlands Irrigation Trust Incorporated.

## Box 1: Methods of water charging

### Area based charging

Area based charging is charged on the area being irrigated, or by other factors such as the crop type and irrigation method (Tsur and Dinar 1997).

### Volumetric charging

Volumetric water charges are based on the volume of water consumed. The sole requirement is a metered count of the volume used by each user (Tsur and Dinar 1997).

### Average cost charging

Average cost charging occurs when fixed and variable cost components are incorporated into a single charge (Goesch 2001).

### Two-part charging

Two-part charging involves the charging of a fixed and variable fee. The fixed fee is equalised to the irrigators' proportionate share of infrastructure fixed costs, while the variable fee represents the marginal cost of water delivery (Goesch 2001).

### Annual access fees

Annual access fees reflect the irrigators' share of the fixed costs of irrigation delivery. However, they can leave irrigation authorities exposed to the financial risk of stranded assets (Gordon, Kemp and Mues 2000).

### Long term contracts

Long term contracts are used in the development of new or refurbished infrastructure. The service provider is obliged to maintain infrastructure, while the irrigator is responsible for their share of the fixed costs, even if their entitlements are sold.

### Exit fees

The fee would represent the net present value of remaining future annual charges that an irrigator would have faced had they remained in the system.

Irrigators that are not part of these trusts (private irrigators) pay annual charges directly to the South Australian River Murray Catchment Board.

Under the Constitution, Australian states are responsible for water management and provide the framework for water use in their state. The COAG reforms in 1995 recommended that delivery charges comply with the principle of full cost recovery, and this was reiterated in the 2004 *National Water Initiative*. Further, under this initiative the states and territories agreed to implement consistent pricing policies within and between regions where it is possible for water rights to be traded in order to facilitate efficient water use and trade (COAG 2004).

In response to these reforms, the states and supply authorities have implemented a variety of charging strategies including volumetric charging regimes and nonvolumetric charging regimes that are based on measurable characteristics such as area based or input–output charging. For each of the ways of differentiating charges, several tariff structures have been applied. These include fixed charges on entitlement or per property, variable charges on allocation or on actual water used, or in combination. Charging regimes for the main irrigation areas under consideration are shown in table 1.

In most Murray Darling irrigation schemes, irrigators face a two-part tariff comprised of a fixed access fee and a variable consumption charge based on the volume of water delivered. There is considerable variation between regions in the proportion of fixed and variable charges. In regions where fixed charges are an unduly large component of delivery charges, they may distort trading patterns if set so high as to move an irrigator out of business. In regions where delivery charges are based mainly on the variable component, it is likely that these fees include not only the costs directly associated with the volume of water delivered in a season, but also a significant share of the capital and overhead costs of delivery. Further, the fixed fee that they do charge tends to be collected through an annual access fee. In both cases, irrigators are not liable for any outstanding fixed costs when water is traded out of the system, leaving those remaining to face higher charges. Depending on the outcomes from interregional trade, therefore, the way in which the supply authority recoups its revenue differential could have a significant impact on regional income and further distort trading patterns (Goesch 2001).

A number of irrigation districts charge irrigators for future asset maintenance and refurbishment. For example, the Coleambally Irrigation Area charges an infrastructure levy for future asset replacement and the Sunland/Golden Heights irrigation trust have infrastructure maintenance reserves for future works. Depending on the level of these charges and whether they are recouped using the fixed or variable component of the delivery charge, this could also have a distortionary effect on water use and trading patterns.

**1 Current water charges in selected regions in the southern Murray Darling Basin** a

| | Current water charges | | | Simulated charges | | |
|---|---|---|---|---|---|---|
| | Fixed fee | | Variable fee | Water availability in model | Share of total charge fixed | Share of total charge variable |
| | $/ML allocated | $ per property | $/ML used | '000 ML | % | % |
| NSW Murray | 18.66 | 0 | 9.49 | 2 005 | 66 | 34 |
| Murrumbidgee | 12.78 | 0 | 12.63 | 2 334 | 50 | 50 |
| Ovens–Murray | 23.52 | 100.00 | 7.98 | 533 | 75 | 25 |
| Goulburn–Broken | 27.62 | 100.00 | 7.74 | 1 413 | 78 | 22 |
| Campaspe | 26.21 | 100.00 | 10.01 | 282 | 73 | 27 |
| Loddon | 21.54 | 100.00 | 7.34 | 871 | 75 | 25 |
| Victorian Mallee | 58.94 | 0 | 48.15 | 472 | 55 | 45 |
| South Australian Riverland | 9.30 | 0 | 38.40 | 494 | 19 | 81 |

**a**. Information was sourced mainly from Murrumbidgee Irrigation; New South Wales Department of Primary Industries; Goulburn–Murray Water; Sunraysia Rural Water; and Central Irrigation Trust.

In the following section, a model is developed representing the incentive for, and constraints on, water trade, to indicate the impact of different charging regimes on the gains from water trade in the southern Murray Darling Basin. It will investigate how irrigator's gains from interregional water trade in the southern Murray Darling Basin vary with the level and form of water delivery charges levied by regional water authorities.

# Empirical analysis of charging in the southern Murray Darling Basin

## Model description

A competitive partial equilibrium model of water markets in the southern Murray Darling Basin was developed to assess the economic impacts of water trade under alternative charging options for water delivery. Eight regions that draw surface water from the Murray River, or its tributaries, for irrigation are represented as demand nodes — Ovens–Murray, Goulburn–Broken, New South Wales Murray, Campaspe, Loddon, Murrumbidgee, Victorian Mallee and the South Australian Riverland. Agricultural enterprises along the river system are integrated through an almost linear annual water flow network. In each region, intraregional trade in water links irrigated activities and land links dryland and irrigated activities. Water trade is the main economic link between all regions in the system.

The model developed belongs to the set of integrated agricultural enterprise and water network models of water supply that are widely used in the applied water policy modeling literature (see, for example, Rosegrant et al. 2000 and Beare and Heaney 2002). An added feature is that the model is expressed in the most general Kuhn–Tucker form (also called the mixed complementarity or primal dual form), which allows policy restrictions on price and quantity to be simultaneously modeled. Hafi et al. (2001) provides a recent example of the use of the integrated primal dual framework in water modeling.

The activities that compete for basinwide water resources as currently specified in the model are horticulture, irrigated crops and irrigated pasture. In addition, dryland crops and pasture activities compete with irrigated activities for land in each region. Each agricultural activity uses capital, labor, land and water to produce an output that gets sold at an exogenously given price. Water and fixed factor rents are used to measure gains in economic efficiency, as these are the returns to river communities above the payments required to keep variable factors of production fully employed over the medium term along the irrigation system.

To maximise efficiency through price signals, the traded price of water ought to reflect all costs in water delivery at the margin. Assuming unit water conveyance costs from the source increase progressively as water moves downstream, the traded price of water should also increase downstream. This market signal is transmitted in interregional trades that value ‘effective water’, where effective water is the actual water delivered plus conveyance losses. However, delivery costs will not simply be a function of transport distance. Conveyance losses can depend on soil types and some areas may, for example, face greater pumping costs than others because of the height of the river bank.

The ability to model efficient water trade is a unique feature of the model. Notably, annual conveyance losses include the evaporation losses from storages that are used to match, within a year, water availability with water requirements. Annual conveyance loss rates also reflect that within a year there are periods with high proportional loss rates, such as in floods, and periods of low proportional loss rates, such as when the river remains within its main channel. Conveyance losses were calibrated to aggregate average loss data for the basin from data provided by the Murray Darling Basin Commission and water flow data from regional gauge data, where possible. Further details of the model specification are given in the appendix.

Land values, water intensities and land use areas were based on the latest version of ABARE’s SALSA model as used in Alexander and Heaney (2003). The SALSA database was constructed from information on land and water use, farm returns and delivery charges for each irrigation area. This information was collected from several sources including ABARE farm survey data, irrigation supply authorities and state governments and aggregated to a regional level.

Water prices were mainly based on indicative permanent water right prices from Marsden Jacob as sourced from Young et al. (2002). Water supply and demand numbers from the SALSA model database were adjusted to be consistent with more recent data available from the Murray Darling Basin Commission's Water Audit Monitoring report for 2000-01, various fact sheets available from the Commission's website and data sourced from the Victorian and New South Wales governments. Indicative water charges were obtained mainly from the various websites of the regional water utilities. Supplementary information on capital rental values was mainly sourced from the Bureau of Transport and Regional Economics (2003).

## Model simulations

The model simulations were structured to assess the economic impacts of interregional water trade under two different water delivery charging regimes. Interregional trade simulates water allocated being traded between regions reflecting profit maximising incentives with the constraints on physical flows specified in the model. The trade simulations are compared to the reference case. In all simulations, delivery charges are based on those that are currently charged in the regions, in accordance with table 1. While there is considerable variability in the proportion of fixed and variable charges in the irrigation regions, it was assumed that these charges reflect the true fixed and variable costs incurred in providing delivery services. This assumption is assessed later in another simulation.

In the first trade simulation any potential change in the level of fixed costs collected by irrigation authorities is recouped through a fixed or nonvolumetric charge. This leads to an optimal pattern of trade. Fixed costs may be recouped through an exit fee (or long term contract) or by increasing the level of fixed access fees paid by irrigators remaining with the region. The latter will increase the average delivery charges faced by each irrigator in regions where water is traded out but will not affect the level or pattern of production unless individual irrigators are driven out of business by the higher nonvolumetric charge.

In the second trade simulation, the shortfall in fixed charge revenue is assumed to be recouped through an increase in variable delivery charges. For regions that export water through trade, this increases the variable delivery charge above the volumetric cost of delivery. Further, the difference between the variable delivery charge and the volumetric cost of delivery increases as the volume of water traded out increases. This will distort the pattern of trade in exporting regions as the incentive for irrigators to trade out of the region increases as trade expands. For regions to which water is traded, the charging regimes are unaltered but average total costs fall within that region as fixed costs are distributed over a greater volume.

In all simulations, the level of trade into the South Australian Riverland and Victorian Mallee does not take into account restrictions or increased costs caused by the impact of salinity. It is also assumed that there is a well functioning market within each region — that is, that all intraregional trades have already taken place. Results for the alternative simulations are shown as changes from the reference case. Regionwide results for the selected areas are presented as totals for the volumetric effects of trade and as average charges for the various charging regimes.

## Simulation results

Changes in regional income, water use and water prices from the reference case for the two simulations are shown in table 2. The findings suggest that the removal of any impediments to trade will result in around 600 gigalitres of additional trade in permanent water entitlements, and an increase in net income of almost $100 million in net present value terms. This reflects, in part, the large sunk investment in on- and off-farm infrastructure. As these assets reach the end of their economic life and environmental demands increase, so will the value of trade.

While changes in regional income as a result of interregional trade are small, importantly, the manner in which supply authorities recoup fixed costs from irrigators remaining in the system after trade has distributional effects on regional income and can distort trading patterns. For example, recouping a shortfall in revenue from fixed charges by means of variable charges reduces regional income in the New South Wales Murray by around $6 million each year in comparison to adjusting fixed charges only. It also results in around 40 gigalitres more water being traded out of the region. Accordingly, this charging regime results in more water trading by importing regions, such as the Goulburn–Broken, than would have occurred under a system of exit fees. Overall, using variable charges to recoup the difference in revenue from fixed charges leads to an efficiency loss from trade of almost $11 million each year.

Recouping a shortfall in revenue from fixed charges by changing the fixed charge regime can be implemented in two ways: through a nonvolumetric charge using an exit fee, or by increasing the level of fixed charges paid by irrigators remaining with the region. The difference in average delivery costs for each region under these two alternatives is presented in table 3. The average cost of delivery will increase in regions that are simulated to trade water out, such as the New South Wales Murray region, no matter whether there is an exit fee to cover fixed costs, and decrease in regions that are simulated to trade water in. Without an exit fee, these effects are accentuated but this regime does not result in changes in the distribution of regional incomes so long as fixed costs are recovered using fixed charges. Failure to use exit fees or long term contracts increases the average delivery costs for the remaining irrigators by around $0.70 per megalitre. This represents a decline in the value of their entitlement of almost 2 per cent.

## 2 Income, water use and water prices, by region

| | | Ovens–Murray | Goulburn–Broken | NSW Murray | Campaspe | Loddon | Murrum-bidgee | Victorian Mallee | South Australia | Overall system |
|---|---|---|---|---|---|---|---|---|---|---|
| **Income** | | | | | | | | | | |
| No interregional trade | $m | 96.0 | 263.4 | 342.2 | 44.5 | 135.9 | 260.7 | 107.0 | 78.5 | 1 328.1 |
| Interregional trade | | | | | | | | | | |
| – fixed cost recovery | $m change | 0.3 | 0.8 | 0.8 | 0.2 | 0.5 | 1.2 | 0.5 | 0.4 | 4.7 |
| – variable cost recovery | $m change | 0.4 | 1.1 | –5.1 | 0.3 | 0.7 | –4.5 | 0.6 | 0.5 | –6.0 |
| **Water use** | | | | | | | | | | |
| No interregional trade | GL | 530 | 1 410 | 2 010 | 280 | 870 | 2 350 | 470 | 490 | 8 390 |
| Interregional trade | | | | | | | | | | |
| – fixed cost recovery | GL change | 80 | 200 | –240 | 50 | 130 | –340 | 60 | 70 | 0 |
| – variable cost recovery | GL change | 100 | 250 | –300 | 60 | 150 | –400 | 70 | 70 | 0 |
| **Water prices** | | | | | | | | | | |
| No interregional trade | $/ML | 52.5 | 52.5 | 37.5 | 52.5 | 52.5 | 37.5 | 62.5 | 57.5 | 50.63 |
| Interregional trade | | | | | | | | | | |
| – fixed cost recovery | $/ML change | –8.3 | –8.3 | 6.7 | –8.3 | –8.3 | 6.7 | –18.3 | –13.3 | –6.4 |
| – variable cost recovery | $/ML change | –9.7 | –9.7 | 5.3 | –9.7 | –9.7 | 5.3 | –19.7 | –14.7 | –7.9 |

## 3 Average delivery charges with interregional trade, with and without exit fees

| | Ovens–Murray | Goulburn–Broken | NSW Murray | Campaspe | Loddon | Murrum-bidgee | Victorian Mallee | South Australia | System average |
|---|---|---|---|---|---|---|---|---|---|
| | $/ML | $/ML | $/ML | $/ML | $/ML | $/ML | $/ML | $/ML | $/ML |
| Exit fees | 29.0 | 32.3 | 30.7 | 33.3 | 26.6 | 27.6 | 100.1 | 46.6 | 35.2 |
| Without exit fees | 28.4 | 31.7 | 31.4 | 32.6 | 26.1 | 28.0 | 99.5 | 46.5 | 35.3 |

## 4 Change in water use with interregional trade under current variable charges versus equal variable charges

| | Ovens–Murray GL | Goulburn–Broken GL | NSW Murray GL | Campaspe GL | Loddon GL | Murrum-bidgee GL | Victorian Mallee GL | South Australia GL | System total GL |
|---|---|---|---|---|---|---|---|---|---|
| Current variable charges | 80 | 200 | –240 | 50 | 130 | –350 | 60 | 70 | 0 |
| Equal variable charges | 30 | 70 | –350 | 30 | 40 | –360 | 300 | 240 | 0 |

Interregional trade is driven by differences in both the marginal value of water on farm — that is, the full opportunity of cost of water — and the difference in variable delivery charges that may or may not reflect differences in true variable delivery costs. In the simulation presented in table 4, it was assumed that true variable delivery costs in each region were equal. This allowed a comparison of the trade impacts resulting from differences in the agricultural returns, as opposed to differences in variable delivery charges. The results of this simulation suggest that differences in variable delivery charges are driving a lot of the trade. For example, under the current charging strategy around 200 gigalitres of water was simulated to be traded into the Goulburn–Broken region, whereas if variable charges were equal, trade into the region would be around 70 gigalitres. While this suggests that the level of variable delivery charges does, in part, drive patterns of trade, this will not lead to a trade distortion if variable delivery charges reflect differences in true variable costs. Nevertheless, given the observed variation in variable delivery charges, this may warrant further investigation.

## Concluding remarks

In the model simulations, water demand is inelastic owing, in part, to sunk investments in infrastructure, and total water entitlements being fixed in aggregate. Under these conditions the gains in regional real income from water trade liberalisation will be small until the end of the economic life of these investments is reached or there is increased demand for environmental management purposes. The regional distortions in income caused by distorted charging policies are also small but sufficient to turn gains from water trade into losses under imposing higher variable charges to recoup fixed charge revenue forgone. The largest real income gains to the basin, and gains to all the selected regions where water trade is liberalised, result when variable charges reflect the volumetric cost of delivery and shortfalls in fixed cost revenue due to trade are recovered through an exit fee or a long term contract.

There are other impediments to achieving efficient trade outcomes in the southern Murray Darling Basin. These include accounting for conveyance losses and externalities, such as salinity.

# Appendix 1: Model description

Hydrological relationships at each node of the Southern Murray Darling river system are specified between inflow from runoff and river flow into the node, return flow from irrigation use at adjacent upstream nodes, irrigation use at the node and river flow from the node. Conveyance losses separated in evaporation losses and losses into subsurface systems are specified as proportions of the river flow from each node. Flow variables represent annual flows. Thus, annual conveyance losses include the evaporation losses from storages that are used to match — within a year — water availability with water requirements. Annual conveyance loss rates also reflect that within a year there are periods with high proportional loss rates, such as in floods, and periods of low proportional loss rates, such as when the river remains within its main channel.

Irrigation water use at each node can be for a range of activities. The activities are currently specified as horticulture, irrigated crops, irrigated pastures, dryland crops, and dryland pastures. Each activity uses capital, labor, land and water to produce an output that gets sold at a fixed gross margin. The production specification is one of fixed proportions for labor and a CRESH function over all the other inputs.

The model can be specified for short run, intermediate or long run analysis. In long run analysis, the annual rental to capital and the annual wage rate are assumed to be given exogenously and to be unaffected by the quantities of capital and labor desired for an irrigation activity. For intermediate analysis some capital stocks, for example horticultural assets, are assumed to be fixed.

For each activity, there is a fixed area of land that is only used in that activity and the associated annual land rental is endogenously determined. The remaining land area at a node can be used in any activity and the annual rental at the node is endogenously determined. In short run analysis, capital is given exogenously and its annual rental is determined endogenously. Substitution parameters of the CRESH production function are specified such that substitution elasticities in long run analysis are larger than or the same as those in short run analysis. From cost minimisation given gross margins net of labor costs, there is a total demand for water for all the activities at a node that is a function of the common user price of water at that node. This demand is given by equation (1) following.

The following hydrological and economic conditions at each node:

## Water demand

(1) $$c_r = c_r(p_r), \text{ for } r = 1, \ldots, R$$

that is, at each node *r*, water use, $c_r$, is a function of the user price, $p_r$. Given the assumptions on the production functions for the irrigation activities, water use at each node is positive and a declining function of price for positive water prices.

## River flow

$$(2) \qquad \sum_{s \in D_r} x_{rs} + c_r = s_r + \sum_{s \in S_r} x_{sr}\left(1 - l_{sr}\right), \text{ for } r = 1,\ldots,R$$

that is, at each node $r$, river flow from the node to all its adjacent downstream nodes plus water use at the node equals inflow from runoff at the node, $s_r$, and river flow from all its adjacent upstream nodes net of proportional conveyance losses.

The model can be used to socialise or explicitly account for conveyance losses. When accounting for conveyance losses the following condition holds

## Pricing for conveyance losses

$$\pi_r \geq \pi_s\left(1 - l_{rs}\right),\ x_{rs}\left(\pi_r - \pi_s\left(1 - l_{rs}\right)\right) = 0 \text{ and}$$
$$x_{rs} \geq 0 \ \textit{for}\ r = 1,\ldots,R-1 \text{ and } s \in D_r;$$
$$\pi_r \geq 0,\ x_r\pi_r = 0 \ \textit{for}\ r = R$$

that is, at each node $r$ other than the last, there is a common price of river flow from the node to the adjacent downstream nodes, $\pi_r$, that cannot be lower than the price of river flow from any of these adjacent downstream nodes net of the cost of conveyance losses to them, while if the price from node $r$ exceeds the price from adjacent downstream node $s$ net of the cost of conveyance losses then there is no river flow from node $r$ to node $s$, and if river flow from node $r$ to node $s$ is positive then the prices at the two nodes differ only by the cost of conveyance losses between them. If the price of the river flow from the last node is positive then there is no flow from that node, and if that river flow is positive then the price will be zero.

## The specification of agriculture in the irrigation regions and activity levels and volumes of inputs used are presented as functions of regional water prices

The approach used is to present, for each activity in a region, the constant returns to scale CRESH production function in its dual form — in terms of output price and all input prices. Volumes of inputs used are then specified, using Shephard's lemma, as functions of output volume, output price and all input prices. Conditions are described that limit the land available for all activities in a region and water market conditions. In this appendix, the water market is characterised by equalised water prices net of delivery charges in a region due to intra-regional trade in water allocations. Delivery charges are exogenously given numbers, although there are applications in which delivery charges vary with trade in allocations reflecting alternative charging policies of water authorities. Finally, exogenously given output price, input prices and input volumes are specified. This results in water demand functions by region.

***The CRESH function in terms of output and input prices***

$$(3)\quad 1 \le \sum_{i=1}^{n} \frac{w_{ijr}(0)}{\rho_{ijr}} \left[ \frac{\lambda_{jr} \, {p_{ijr}}\big/{p_{ijr}(0)}}{\lambda_{jr}(0) \, {p_{jr}}\big/{p_{jr}(0)}} \right]^{1-\sigma_{ijr}} \Bigg/ \sum_{i=1}^{n} \frac{w_{ijr}(0)}{\rho_{ijr}}$$, where $\lambda_{jr}$ is implicitly defined

by $\dfrac{\lambda_{jr}}{\lambda_{jr}(0)} = \sum_{i=1}^{n} w_{ijr}(0) \left[ \dfrac{\lambda_{jr}}{\lambda_{jr}(0)} \dfrac{{p_{ijr}}\big/{p_{ijr}(0)}}{{p_{jr}}\big/{p_{jr}(0)}} \right]^{1-\sigma_{ijr}}$ and $w_{ijr}(0) = \dfrac{p_{ijr}(0) q_{ijr}(0)}{p_{jr}(0) q_{jr}(0)}$,

where $p_{jr}(0) q_{jr}(0) = \sum_{i} p_{ijr}(0) q_{ijr}(0)$, for $\rho_{ijr} < 1$ and $\sigma_{ijr} = (1 - \rho_{ijr})^{-1} > 0$ and for

Further, if (3) is satisfied with strict inequality, then the non-negative activity level $x_{jr}$ is zero, and if the activity level is positive, then (3) is satisfied with equality.

***Input use equations using Shephard's lemma***

(4) $$x_{ijr} = x_{jr} \frac{\partial p_{jr}}{\partial p_{ijr}}, \text{ for } \forall i, j, r$$

That is, the volume used of any input is proportional to output and depends also on output price and all input prices.

## Land use and rents

(5) $$x_{ijr} \le \underline{x}_{ijr}, p_{ijr}\left(x_{ijr} - \underline{x}_{ijr}\right) = 0 \text{ and } p_{ijr} \ge \text{, for } \forall r, j \text{ and}$$

where *i* is land that is specific to activity *j* in region *r*.

For each activity in each region, use of land that is specific to this activity cannot exceed the available area of this land. If the area used is less than the area available, then the annual rent for this land is zero, and if the land rent is positive then all this type of land is used.

## Land that can be reallocated between activities in a region

(6) $$\sum_{j} x_{ijr} \le \underline{x}_{ir}, \; p_{ir}\left( \sum_{j} x_{ijr} - \underline{x}_{ir} \right) = 0 \text{ and } p_{ir} \ge 0 \text{, for } \forall r \text{ and}$$

where *i* is land that can be reallocated between activities in a region

In each region, the total area of land that can be reallocated between activities is given. If the area used is less than the area available, then the annual rent for this type of land is zero, and if the land rent is positive then all the available area is used.

(7) $p_{ijr} = p_{ir}$, for $\forall j, r$ and

where $i$ is land that can be reallocated between activities in a region

Trade in land that can be reallocated between activities in a region results in equalised annual rents for all activities in the region.

## Water prices

(8) $p_{ijr} = p_{ir}$, for $\forall j, r$ and where $i$ is water

Trade in water within a region results in equalised water prices to users for all the activities in the region.

(9) $p_{ir} = p_r = \pi_r + d_r$, for $\forall r$ and where $i$ is water

The user price of water in region $r$ equals the water rent in the region plus a volumetric delivery charge.

## Capital

***Capital rents (in long run simulations)***

(10) $p_{ijr} = \underline{p}_{ijr}$, for $\forall j, r$ and where $i$ is capital

The annual rent to capital is given and independent of quantities of capital used.

***Capital quantities (in short run simulations)***

(11) $x_{ijr} = \underline{x}_{ijr}$, for and where $i$ is capital

The quantities of capital used are the quantities available in the short run.

## Labor

(12) $p_{ijr} = \underline{p}_{ijr}$, for $\forall j, r$ and for i is labor

The annual rent to labor is given and independent of quantities of labor used. This assumption is made in both short run and long run simulations.

(13) $x_{ijr} = a_{ijr} x_{jr}$, for $\forall j, r$ and where i is labor

The quantity of labor used in an activity in a region is proportional to the activity level. This assumption is made in both short run and long run simulations.

The labor assumptions are implemented by regarding all prices of activities in the analysis, $p_{jr}$ , as per unit returns net of intermediate input costs and labor costs (that is, per unit gross margins less the now given per unit labor costs).

## Notation

### *Variables*

$x_{jr}$ volume of output of activity *j* in region *r*

$x_{ijr}$ volume of input *i* used in activity *j* in region *r*

$p_{jr}$ price of output (per unit gross margin net of per unit labor costs) of activity *j* in region *r*

$p_{ijr}$ price (annual rent) of input *i* used in activity *j* in region *r*

$\lambda_{jr}$ auxiliary variable in CRESH implicit price function

$p_{ir}$ common price of input *i* for use in all activities in region r

$c_r$ volume of water used in region *r*

$p_r$ price (annual rent) of water used in region *r*

$x_{rs}$ volume of water flow from node (region) *r* to node (region) *s*

$s_r$ volume of water inflow from runoff into node (region) *r*

$\pi_r$ price (annual rent) of river flow in region *r*

### *Parameters and initial values*

$l_{rs}$ proportion of annual river flow from node *r* to node *s* lost in conveyance through evaporation and losses to subsurface systems

$w_{ijr}(0)$ share of input *i* in cost of activity *j* in region *r* in base year

$\rho_{ijr}$ substitution parameter in CRESH function for input *i* used in activity *j* in region *r*

$\sigma_{ijr}$ substitution elasticity in CRESH function for input *i* used in activity *j* in region *r*

$p_{ijr}(0)$ price of input *i* use in activity *j* in region *r* in base year

$p_{jr}(0)$ price of activity *j* in region *r* in base year

$q_{ijr}(0)$ volume of input *i* used in activity *j* in region *r* in base year

$q_{jr}(0)$ volume of activity *j* in region *r* in base year

$\lambda_{jr}(0)$ value of auxiliary variable in CRESH implicit price function in base year

$d_r$ volumetric delivery charge for water in region *r*

$\underline{x}_{ijr}$ exogenously specified volume of input *i* used in activity *j* in region *r*, for *i* = land specific to an activity, and in the short run for capital

$\underline{x}_{ir}$ exogenously specified volume of input *i* in region *r*, for *i* = land available for allocation among activities

$\underline{p}_{ijr}$ exogenously specified price of input *i* used in activity *j* in region *r*, for *i* = labor, and in the long run for capital

$a_{ijr}$ fixed requirements of input *i* per unit of output of activity *j* in region *r*, for *i* = labor

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