The Australian Journal of Agricultural and Resource Economics, 46:3, pp. 347–366

Capturing benefits from water entitlement trade in salinity affected areas: A role for trading houses?

Rosalyn Bell[†]

While there is potential for substantial benefits from water entitlement trade, external effects such as salinity may mean that traders cannot capture these benefits. This paper demonstrates that by creating a trading house as a single seller of water entitlements, with trade profits distributed to buyers, it is possible to achieve an allocation of entitlements which gives a social outcome higher than that possible from atomistic competition for entitlements. Such an outcome may be comparable to an optimally set uniform charge for water entitlements, but the trading house mechanism has the advantage that it makes use of trade to generate information on the optimal level of charging in the presence of salinity.

1. Background

The potential net benefits of trade in water entitlements have been estimated to be around 5 per cent of the total gross margin per year to irrigators in the Murray–Darling Basin (Hall *et al*. 1994). With diversions from regulated rivers in the basin capped since the mid 1990s and increasing demand for water for new developments, trade in temporary entitlements is rapidly becoming the principal means of reallocating scarce water resources. In the Goulburn–Murray region, for example, only 43 temporary trades in water entitlements occurred in 1989–1990, representing 22 gigalitres of water. By 1999–2000, this had risen to around 3600 temporary trades, or about 204 gigalitres (Goulburn Murray Water 2000).

Bilateral trades, handled directly by irrigators, comprise the bulk of temporary water trade. However, formal markets or water exchanges have emerged in those areas where most of Australia's irrigation water is used and traded (New South Wales Department of Land 1999; Chandler 2000). For example, the Southern Riverina Water Exchange was established in 1997 to service irrigators in the Murray district, and the Northern Victoria

[†] Rosalyn Bell, Senior Economist, Australian Bureau of Agricultural and Resource Economics, Canberra, Australia.

Water Exchange was formed in 1998 for trade by irrigators in the Goulburn–Murray and Sunraysia regions.[1] A statewide water exchange is planned to be operational in Victoria by the start of the 2002–2003 irrigation season. These water exchanges bring buyers and sellers together on a regular basis, implement state and regional restrictions on trade and provide information on traded prices.

In order for trade to lead to a socially efficient allocation of water, water entitlements need to be defined such that the full costs and benefits of all water use are assigned to a water entitlement holder. That is, every unit of water, at each point in the storage, delivery and hydrological system where it has some value, needs to be under entitlement. However, the common pool nature of water within the storage systems and delivery channels, and the diffuse and uncertain nature of impacts associated with water use, means that water entitlements are unlikely to ever be defined in terms of full costs and benefits of water use (Bell and Beare 2000). Use of water for irrigation, for example, can have external impacts on both the volume and salinity of water available to downstream users and the riverine environment more generally (Murray–Darling Basin Commission 1999a). Trade in imperfectly defined entitlements that ignores these externalities can potentially result in an allocation of water that increases the external salinity costs of water use by more than the gain in productive use of the water entitlement, thereby costing society more than it gains from trade. Water markets are now at a point where it is important to assess the property rights, structure and institutional frameworks that may be necessary to ensure that trade results in an allocation of water resources that improves social welfare.

1.1 Allocative efficiency of trade

In simplistic terms, trade in water entitlements will result in water shifting toward those uses in which it yields the highest marginal return, net of transfer costs. However, the allocative efficiency of trade will hinge on the extent to which markets are able to account for a number of factors that affect the value of water used. These factors include the timing of water use, system evaporative losses, and return flows which affect both the quantity and quality of water available to other users.

Beare and Bell (1998) demonstrate that trade is unlikely to lead to an efficient allocation of water entitlements when the value of water use varies

[1] Around 72 gigalitres of water was traded via the Southern Riverina Water Exchange in the 2000–2001 season (Murray Irrigation 2001). The Northern Victoria Water Exchange handled 60 gigalitres (31 per cent) of the region's temporary water trade in 2000–2001 (Goulburn Murray Water 2001).

throughout the irrigation season and the timing of delivery is constrained by the capacity of the delivery system. For irrigators that use water for relatively low valued pasture or cropping activities, the traded price of this entitlement may be well below the marginal returns associated with expanding higher valued activities that require additional water during the peak irrigation season. A water entitlement purchased from an individual who uses that water in the off-season may not convey to the purchaser a guaranteed access right in the peak season. Beare and Bell also note that the failure to link water entitlements to the use of distribution infrastructure at a particular time of the year can mean that water trade results in a stranding of irrigation assets.[2] In recognition of this potential problem, there has been a general reluctance to allow trade between regions that do not share delivery infrastructure.[3]

Further inhibiting an efficient allocation of water entitlements through trade is the existence of substantial evaporative losses. There may be large evaporative losses in transporting water through open channels to farms near the end of an irrigation system compared with delivery to farms close to water storages. There may also be significant quantities of water used but not accurately measured. If differences in delivery costs between farms are not reflected by differences in delivery charges, then some irrigators will pay a delivery charge in excess of the marginal cost of delivery to them, while others pay less (Hafi *et al.* 2001). The resulting allocation of water is unlikely to be efficient, and entitlement trade that does not take these differences in delivery costs into account may not improve it.

Not explicitly including rights to return flows within the scope of water entitlements may also reduce the efficiency with which a market can allocate water. A return flow is the water associated with an irrigation diversion that returns to the hydrological system as surface runoff from flood irrigation, irrigation drainage, channel seepage or ground water discharge from irrigation areas. Irrigators presently hold an implicit right to return flows in that they can trade water entitlements without consideration of downstream externalities (Beare and Heaney 2001). To the extent that these downstream impacts are significant, the allocation of water entitlements will be inefficient.

[2] The stranding of assets is an extreme situation that may arise, for example, if transfers of entitlements out of an irrigation area leaves an irrigation authority with large fixed infrastructure costs but no customers.

[3] For example, irrigation schemes on the Macquarie River in NSW prohibit out-of-scheme permanent trade and in Victorian, water authorities can refuse out of area permanent transfers if annual net transfers exceed two per cent of water rights in the sourced area.

1.2 Salinity as an externality of water use

Return flows may be associated with positive or negative externalities to other water users and the environment. The principal positive externality of return flows is an increase in the volume of river flows downstream. A common negative externality associated with return flows is the problem of irrigation-induced salinity. Increased return flows from irrigation areas with relatively high groundwater salt concentrations, or reduced return flows from areas with relatively low groundwater salinity, may raise the salinity of streams lower in the system. The extent to which return flows affect stream salinity depends on several factors, including groundwater recharge rates and the salinity of aquifers beneath irrigation areas. In the Murray–Darling Basin, both groundwater and stream salinity levels tend to increase downriver, with groundwater salinity approaching the salt concentration of seawater in low lying areas of South Australia (MDBC 1999b).

Beare and Heaney (2001) describe the impact that water trade may have on river salinity. Trade that moves water from an irrigation area with relatively low groundwater recharge rates and low groundwater salinity to a downstream region with high recharge rates and groundwater salinity can produce a series of impacts on stream salinity. Immediately downstream of the seller, the transfer may increase stream flows and reduce river salt concentration. However, as groundwater recharge rates are higher in the downstream area, surface runoff will be lower, reducing the volume of return flows available downstream of the buyer. Further, as groundwater salinity is higher downstream, salt concentrations will be increased as more salt is transported to the river system.

Increased salinity reduces the productive capacity of agricultural resources and can adversely affect infrastructure such as roads and the quality of environmental assets such as wetlands. River salinity in parts of the Murray–Darling Basin is already at concentrations at which yield reductions can occur for irrigated crops. The problem is expected to become more widespread throughout the basin over the next 100 years (MDBC 1999b).

At a state-wide level, the incentive for upstream states in the Murray–Darling Basin to regulate salinity has been promoted by the introduction of the Salinity and Drainage Strategy (MDBC 1999a). States earn credits by funding the construction of salt interception schemes or other methods of reducing stream salinity, and lose credits by allowing actions which increase salinity. In Victoria, areas with high salinity impact have been identified and water trade into these areas is prohibited. In addition, a levy has been introduced on water transferred into the Sunraysia district in the Victorian Mallee (Young *et al.* 2000).

While such schemes have had some success in reducing stream salinity, the transactions costs associated with establishing property rights that fully internalise the effects of return flows on downstream users are likely to be prohibitive. Beare and Heaney (2001) suggest regulation to alter the price at which water entitlements trade, in order to reflect the costs or benefits associated with downstream changes in river salinity as a result of trade. An alternative approach that may require less information would be to modify the market structure so that external costs will be at least partly internalised, without continuous monitoring and intervention. Such an approach is consistent with intergovernmental agreement on the National Action Plan on Salinity and Water Quality (AFFA 2001) and is the focus of this article.

The remainder of the paper explores the scope for water entitlement markets to improve social welfare, through a reallocation of entitlements, when there are significant external salinity costs associated with water use. Given the often diffuse spatial nature of salinity, the effectiveness of markets will depend on how much information those trading have on the potential salinity outcomes of trade. Such information may be apparent if entitlements are defined spatially, or alternatively, may become evident to traders as the market operates over time. The ability of markets to generate information on the salinity outcomes of trade is discussed and a simulation model is developed to explore the effectiveness of alternative market structures in improving social welfare.

2. Optimal and second-best trade outcomes

2.1 Spatially differentiated entitlements

The construction of institutional arrangements in which agents face the full benefits and costs associated with their resource use decisions is a notable economic objective of resource policy. Where the location of resource users is important, such that the use of a shared resource by one agent affects the value of the resource to other agents, a policy mechanism which differentiates among resource users according to their location is essential if an efficient allocation of the resource is to be achieved.

Trade in water entitlements is a means by which water users can adjust their level of use between periods within a market framework. Entitlements that differentiate between agents according to the external impacts of water use are essential if the costs and benefits of water use are to be fully internalised (Montgomery 1972). Trade in spatially differentiated water entitlements will yield an optimal water allocation, equivalent to setting a Pigouvian or site-specific charge, under the following conditions. First, entitlements must be defined at each site affected by water use. Second, agents must hold entitlements for each site that their water use affects. For example, if an agent's use of water impacts on several downstream sites, then the agent must hold an entitlement with the right to impact on each of these downstream sites. Third, the market for entitlements must be competitive at each site: that is, perfect and complete information; buyers and sellers unable to influence market outcomes individually or collusively; free entry and exit to the market with new entrants trading on the same terms as existing traders; and fully divisible entitlements.

In a market for water entitlements, this would require information on the value of an additional unit of water to each agent in the market and the costs and benefits to other agents and to environmental assets associated with any impacts of water use, such as salinity damage. With seasonal and economic variations in production conditions, this information would be required at each point in time that a trade occurs. The transactions costs of establishing such a spatially differentiated scheme are likely to be prohibitively high (Atkinson and Tietenberg 1987; Hanley *et al.* 1997). Hence, an entitlement scheme based on spatially undifferentiated entitlements is potentially a more practical instrument for improving water entitlement allocation.

2.2 Spatially undifferentiated entitlements

A spatially undifferentiated entitlement scheme is equivalent, in terms of the aggregate outcome to society, to the implementation of an optimally-set uniform charge on water entitlements. As this is a second best policy instrument, it is important to ascertain the effectiveness of such a scheme and to attempt to establish market conditions that will facilitate an outcome for water entitlement allocation as close as possible to optimal.

A potential benefit of a tradable entitlement scheme is that trade may generate information regarding a socially preferred level of use, as well as a more efficient distribution of entitlements. This is a potentially attractive option to policy makers in that they may only need to establish a set of trading arrangements to achieve a better resource management outcome. Individuals can retain their current level of entitlements, bear the information and transactions costs and realise any benefits of trade.

A competitive market with a large number of buyers and sellers has long been accepted in economic theory to be an appropriate market structure to generate the information necessary for trade to result in an efficient allocation. This presumes that buyers and sellers perceive and incur the full costs and benefits of trade. The presence of external costs and benefits can prevent a competitive market from achieving a socially efficient outcome.

The difficulty in setting up trading arrangements in water entitlement networks is that the value of an entitlement will depend not just on price but on the locations of other agents who buy and sell water. Purchasing water entitlements from an upstream producer along a river may have a substantially different outcome for salinity than purchasing the same quantity of water entitlements from a producer downstream. The productivity of the water associated with entitlements purchased may be increased, for example, by purchasing from a region that has relatively high recharge rates and groundwater salinity. In such an instance, an individual's marginal return from a transaction may not be equal to the market price as the marginal return will vary depending on who is buying or selling. Green (1977) establishes that competitive market equilibrium may not exist where there is quantity dependence and agents are only able to observe prices. That is, if in order to calculate their optimal actions, agents need to observe not only market prices but also the salinity outcome from trade, then there may be no achievable market equilibrium. The ability of markets to generate such information can differ significantly between alternative market structures.

3. Market structure and the outcome of trade

In order to ascertain the effectiveness of alternative water entitlement trading mechanisms in internalising externalities such as salinity, water use decisions and impacts must be considered separately for each trading agent. This essentially requires consideration of each trader as a self-advancing agent. An agent is unable to take into account the full external benefits and costs of his water use decisions, but recognises that water use decisions of other unknown and self-advancing agents impact on the productivity of his own water use. In this way, the externalities inherent in the network of water use can be modelled explicitly. Multi-agent based approaches to the modelling of economic problems have been an active area of research in recent years (e.g., Boutilier *et al.* 1997; Hernandez Iglesias and Lopez Paredes 1999).

Consider, for example, a number of identical agents that access water sequentially along a river and use of the water in production raises the salt concentration of water available to agents further downstream. This example is described algebraically in the appendix.

Agents may be either individual irrigators, aggregations of water users within the same region, or simply sites that use water and incur salinity costs associated with water use by other agents. The impact of water use on salinity, and of salinity on the productivity of water use downstream is assumed, for simplicity, to be instantaneous. Agents are assumed to be price takers in the market for their production.

Agents have an initial entitlement to water and are able to trade their entitlement each year. An entitlement is assumed to define the quantity of water that can be used on the agent's site. Agents are assumed to be able to purchase water to completely fulfil the entitlement by entering a separate water market.

Each agent develops a trading strategy that maximises its own individual net revenue from production and trade, and is only able to observe market price and the impact of salinity at its own location. The quantity of water entitlements traded and the price at which they exchange will be determined largely by the structure of the market in which trade occurs and the information that is available to market participants.

3.1 Atomistic competition example

Suppose that the water entitlement market operates as an atomistic competition – that is, it is composed of a number of small agents who can either buy or sell water entitlements, depending on the expected return from water use compared with trade. Trade occurs through a sealed bid double auction in which entitlements are distributed to the highest bidding agents first until the water market is cleared at a single trade price (Wilson 1985; Satterthwaite and Williams 1989).[4] Harris and Raviv (1981) note that in uniform price auctions bidders face uncertainty with respect to both acceptance and price. However, Smith (1982) reports that knowledge of valuations and costs of all agents is neither necessary nor sufficient for rapid convergence of allocations and prices in a double auction.

Agents are assumed to start with no information on the value of an entitlement, but learn through a series of market trials, to formulate a bid that will maximise their own expected net revenue, given a range of strategies that other agents may adopt (this process is detailed in Appendix I). The actual trade outcome is that which results from the market resolution of the set of agent's final bids.[5]

[4] The uniform price double auction approach is currently used for temporary trades undertaken through the Northern Victoria Water Exchange (New South Wales Department of Land and Water Conservation 1999). The clearing price is set to maximise the volume of water sold, given volumes available, prices which sellers wish to receive and prices which buyers wish to pay. The exchange operates weekly during the irrigation season.

[5] Traders could be expected to have some information on the value of a water entitlement in their production activities, given that irrigation has been undertaken for many decades in those areas of Australia where most trade in water entitlements occurs. Any information that agents utilise in formulating bids may reduce the number of market trials necessary for an agent to derive a bid that maximises their expected net revenue.

The effectiveness of trade is measured by the proportion of total benefits that are captured by traders, with maximum benefits achievable through the imposition of a site-specific water entitlement charge. These benefits are in the form of an increase in the value of water used in production by downstream agents. Agents upstream may receive higher revenue from water entitlement sales, but at a society level this may be offset by the higher cost of entitlement purchases by those downstream. It is important to note that a lack of information will mean that the market in water entitlements is not perfectly competitive and so the outcome of trade is unlikely to be optimal. Asymmetry of information may even provide some agents with market power. For example, agents at the top of a river system know that any trade they undertake will not impact on the productivity of their own water use because trade will necessarily occur with an agent downstream. However, agents part way down a river system may not know if a transaction will shift water use upstream or downstream of their own location.

In such an example, trade in water entitlements will not result in an efficient allocation of entitlements. Bell and Beare (2002) demonstrate this for alternative spatial configurations of traders in the context of site specific pollution emission permits. Using the river system example, if an agent at the bottom of the network purchases water from one at the top of the network this may convey a benefit to those agents in the middle of the network, as a reduction in return flows from the top agent may have salinity benefits to those in the middle as well as the purchaser at the bottom. As the bottom agent does not capture the full benefits of trade with the top agent, the price that the bottom agent would be willing to pay will not be sufficient as to result in an optimal distribution of water. In the absence of cooperation between agents, the jointness creates a public externality in trade.

Of particular interest here is how close to the optimal outcome (associated with a site specific entitlement charge) the outcome of atomistic competition may be, and how robust this result is to the diffuseness of the salinity problem, as represented by the number of participants in the entitlement market.

From figure 1, it can be seen that as the number of market participants was increased (or equivalently, with an increase in the number of sites that incur salinity costs associated with water use), the overall effectiveness of a simple tradable entitlement scheme declined substantially. That the double auction gives a close to optimal result with few agents is perhaps not surprising. Smith (1982) reports experiments in which allocations and prices converge to the competitive equilibrium outcome with six to eight bidders and two sellers. The more agents there are, the more difficult it is for each

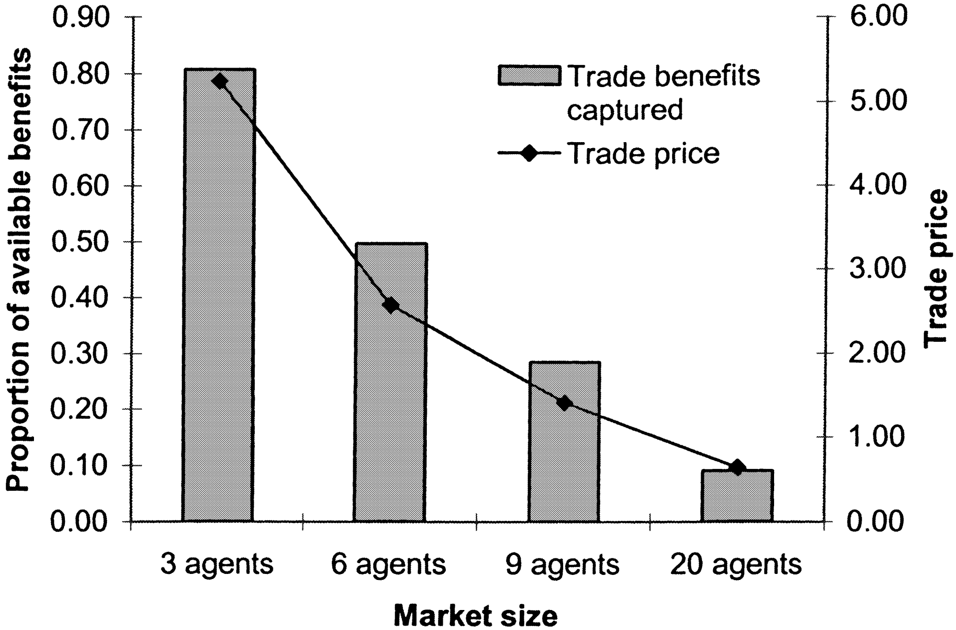

Figure 1 Impact of market size on atomistic competition

agent to isolate the impact of its own trading strategy. This problem has been found to arise in other multi-unit auction experiments, but is exacerbated here by the uncertainty created by the presence of production externalities.[6] For example, increased stream salinisation as a result of higher water use by one agent may impact on a group of agents or sites downstream. This increases the extent of the externality and makes it more difficult for those agents downstream to determine a trading strategy that reduces the salinity costs that they incur. No single agent is able to identify and capture the full benefits of trade between different locations. Hence, in the absence of cooperation between affected agents, the price each agent is willing to pay for an entitlement is lower than it would be if that agent were able to capture the full benefits of reduced salinity.

The expected traded price of entitlements drops sharply as the number of market participants rises, reflecting the inability of individual agents to identify and capture the benefits of reduced salinity through entitlement purchases. If the impact of water use on salinity is lagged in time, it is even more difficult for agents to identify the benefits of a reduction in salinity.

[6] Smith (1987) reports that multi-unit auction markets appear to be less effective than single unit auction markets in disciplining (with failure experiences) those strategies which depart from the dominant strategy.

To internalise spatially dependent externalities through trade in water entitlements, the price discovery process must eventually provide some understanding of the economic impacts of the physical externality, which in turn allows an improvement in the level and distribution of resource access or use. However, provision of such information is not characteristic of a competitive market in which rents associated with reducing the net cost of an externality are competed away. To achieve a more efficient distribution of entitlements, the trade process must generate sufficient information to enable agents to identify and capture these rents. As the number of agents in the market increases, the need for an alternative market structure to facilitate this process becomes imperative.

3.2 Centralised trading house example

One option to enable traders to capture the rent associated with a reduction in the cost of externalities is to artificially reduce the number of traders in the market. This can be achieved by reducing the market to a single seller through the establishment of a central trading house. Under such a scheme, all agents would surrender their entitlements to a central trading house that would simply seek to maximise its returns from the sale of entitlements, and distribute these returns back to agents.[7] The shares of agents in the trading house are critical to the general acceptability of the scheme by agents and the efficiency of the trade outcome. One option would be for agents to have equal shares in the trading house. An alternative is for agents to hold shares in proportion to the entitlements surrendered (which may, in turn, be based on use of water pre-trade).

Non-atomistic market structures enable price experimentation in a market and may generate information on the salinity benefits and costs of a redistribution in water entitlements. This is analogous to the way in which a monopolist can gain and exploit information on the elasticity of demand through, for example, price experiments. However, here the use of this information in setting the price at which entitlements trade may enable an improvement in the distribution of entitlements and the level of salinity.[8] The idea that a monopoly is able to generate and use more information than a

[7] The surrender of all entitlements to a trading house, regardless of whether or not agents require more or less water than their entitlement, may not be a preferred approach for some existing entitlement holders but may mean that new developments find it easier to obtain water. If, on the other hand, only those intending to undertake temporary trade surrendered their entitlements to the trading house, then the benefits available from a reduction in the externality are likely to be significantly reduced.

[8] It may also be necessary to ensure that the trading house is not able misuse this information in order to generate profits in some other sector of the economy.

competitive market is not new. Demsetz (1969) demonstrated that the incentive to generate information for technological advancement is at least as great under a monopoly as in a competitive industry. Mason (2000) showed that, based on a dynamic market for a durable consumer good, when network externalities are large a monopolist may be socially preferable to individual producers.

The principal advantage that a trading house introduces to water entitlement trade when there exists an externality is that water prices may be set above (and production and resulting externalities below) those associated with atomistic competition in which traders compete away any available rents associated with a reduction in salinity (see Carlton and Perloff 1990 for a discussion of monopoly and competition in markets with externalities). To the extent that water use increases the cost of salinity, and salinity reduces the net benefits from water use, then a reduction in water use will provide benefits to society.

In attempting to maximise its revenue from entitlement sales, the trading house has available to it the minimum price at which it will sell an entitlement as its decision variable. At higher prices, less water may be used by all – but most importantly, by those upstream whose water use has the largest external costs. A redistribution of entitlements from upstream to downstream agents reduces the salinity cost that upstream agents impose on those downstream. The productivity of water in production does not change for those upstream, but increases for those downstream. Reflecting this, those downstream would be willing to pay a higher price for an entitlement. Provided that each agent's bids strictly increase with their valuation of entitlements (and all are equally risk averse), the auction outcome will result in entitlements going to bidders with the highest valuations (Vickrey 1961; Kagel and Levin 2001). In this way, a trading house is able to facilitate a redistribution of entitlements from upstream agents to downstream agents.

Information required by the trading house to achieve such an outcome is the initial distribution of entitlements, agents' bids for the purchase of entitlements and the revenue from entitlement sales. Agents, in the process of acquiring water entitlements, will supply the first two items of information. Information on the net revenue outcome of trade is simply an outcome of trade, evident to the trading house as the single entitlement seller. This information is more readily determined than information on diffuse salinity benefits and costs that is necessary for an efficient outcome under atomistic competition.

In the stylised example, with a central trading house as a single seller of entitlements, and profit from trade distributed to agents in proportion to entitlements surrendered, up to 90 per cent of the total potential benefits (that is, the potential increase in the value of water used in production) are captured by agents. This is significantly higher than the proportion of benefits captured through atomistic competition trade in entitlements

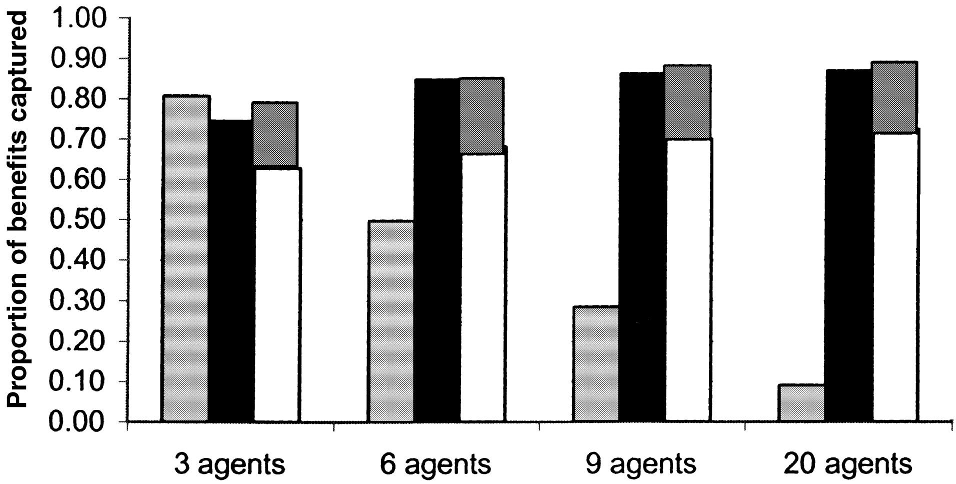

Figure 2 Benefits captured from a reallocation of water. □ Tradable entitlements with atomistic competition; ■ Tradable entitlements with trading house; □ Uniform charge (benefits to agents); ■ Uniform charge (revenue to collector)

(figure 2). The superiority of the central trading house structure over atomistic competition is accentuated as the number of water buyers, or the number of salinity affected sites, increases.

In the example, water use is lower overall when there is a trading house than under atomistic competition, indicating that there are benefits to retiring entitlements from use in the system (particularly from agents near the top of the system). Individual agents trading atomistically are unable to perceive the benefits of such action. Consequently, their offer prices for entitlements do not reflect these potential gains, nor do they realise the full benefit of retiring entitlements. Consistent with this, the traded price of entitlements is higher when there is a trading house than under atomistic competition.

Despite retiring entitlements from use in the system, there are sufficient funds generated by trade for the trading house outcome to be a Pareto improvement over both the no-trade situation and the atomistic competition outcome for more than three agents. That is, under the trading house structure, agents at the top of the river network will have a larger proportion of their net revenue sourced from water entitlement sales, while those at the bottom of the network will have a larger proportion of net revenue sourced from production.

The outcome with the trading house is comparable to that achievable under a uniform charge scheme (figure 2). However, the information and monitoring required to achieve an optimal uniform charge may make it a less favourable option than market-based options. The principal limitation of uniform charges compared with tradeable entitlements is that in order to set an optimal uniform charge (either each period, or in an iterative manner with convergence toward an optimal level), the policy maker needs to know the agent specific production information and details of external costs of each agent at each point in time.

The impact of a uniform charge on income distribution may be quite different to the outcome under a tradable entitlement scheme. Unless charge revenue is returned to agents in fixed and predetermined proportions, the income distribution impacts associated with a charge may make it a less favourable option for agents than a tradable entitlements scheme in which agents receive a proportion of the returns made by a central seller of entitlements (figure 2).

4. Concluding remarks

While there is potential for substantial benefits from trade in water entitlements, the existence of external effects such as salinity may mean that much of these benefits cannot be realised by those trading. The value of a traded water entitlement will depend not just on price, but on the salinity outcome associated with trade. Where the external costs and benefits associated with water use are significant, there may be a role for resource managers and policy makers to create institutional arrangements that facilitate an internalising of salinity costs. State and Federal governments in Australia have committed to greater use of market-based solutions to salinity and water allocation problems. This paper has explored the scope for water entitlement markets to improve social welfare through a reallocation of entitlements, when there exist significant external salinity costs associated with water use.

The diffuse nature of salinity and the spatially undifferentiated definition of entitlements will mean that information on salinity impacts is unlikely to be discernible through a water entitlement market that operates with a number of buyers and sellers. This inability of individual traders to identify and fully capture the benefits of reduced salinity (and costs of increased salinity) may mean that trade does not actually increase the total net benefits of affected water users. This is particularly a problem as the number of atomistic traders in the market increases. One option that is proposed in this paper to increase the benefits captured from water entitlement trade is to establish a centralised trading house.

With a central trading house as a single seller of entitlements, and with profit from trade distributed to agents in proportion to entitlements surrendered, it was demonstrated that a trading house structure enables price experimentation and thereby can generate information on the salinity benefits and costs of a redistribution in water entitlements. With a trading house, an allocation of water entitlements can be achieved which gives a social outcome higher than that possible from atomistic competition for entitlements.

The formula by which trading house profits are distributed to water traders is crucial to the acceptability of such a structure in the market. In the stylised example presented in this paper, profits were distributed to agents in proportion to entitlements surrendered. In such a case, trade alone was found to be insufficient to result in a Pareto improvement over either the no-trade situation or the atomistic competition outcome. However, trade with a trading house did generate sufficient funds to ensure that with compensation to those agents contributing the most to salinity reduction, this option would be the preferred market structure.

One of the principal limitations of the trading house scheme as applied here is the need for a series of market trials in order to enable agents to learn a bidding strategy that maximizes their net revenue. If traders have some information on the value of a water entitlement in their production activities, then use of this information in formulating bids may reduce the time it takes agents to locate a bidding strategy that maximises their net revenue. However, it is important to consider the objective of the exercise – that of increasing the benefits derived from water entitlement trade by internalising the salinity costs of water use – and alternative approaches that policy makers may adopt to achieve this goal. With less than perfect information, a single trial with the trading house structure is analogous to a single attempt by a policy maker at setting the optimal level of a uniform charge on entitlements. However, the trading house has the advantages that it may be preferable in terms of income distribution consequences, and it may have lower monitoring and information costs.

Ultimately, the extent to which a trading house can improve social welfare by a reallocation of water entitlements, compared with the allocation that would result from atomistic competition, will vary between regions. In regions where water users neither contribute to salinity levels nor incur salinity costs as a significant part of production costs, the introduction of measures which raise water prices and reduce water use in production may generate costs which exceed the benefits of any salinity reduction. However, in those regions where water use contributes significantly to increased salinity levels and the costs of salinity are relatively high, the introduction of a trading house may provide a substantial increase in benefits to water traders.

References

Agriculture, Fisheries and Forestry, Australia 2001, *National action plan for salinity and water quality: our vital resources*. [Online]. Available http://www.affa.gov.au

Atkinson, S. and Tietenberg, T. 1987, 'Economic implications of emissions trading rules for local and regional pollutants', *Canadian Journal of Economics*, vol. 20, pp. 370–386.
Beare, S. and Bell, R. 1998, 'Efficiency of water use and access rights to infrastructure', *Australian Commodities*, vol. 5(4), pp. 494–503.
Beare, S. and Heaney, A. 2001, 'Water trade and irrigation – defining property rights to return flows', *Australian Commodities*, vol. 8(2), pp. 339–348.
Bell, R. and Beare, S. 2000, 'Salinity targets in the Murray–Darling Basin', *Australian Commodities*, vol. 7(2), pp. 348–356.
Bell, R. and Beare, S. 2002, 'Emulating trade in emissions permits: an application of genetic algorithms', in Shu-Heng Chen (ed.), *Evolutionary computation in economics and finance*, Springer Verlag, New York, pp. 159–174. (In press).
Boutilier, C., Shoham, Y. and Wellman, M. 1997, 'Economic principles of multi-agent systems', *Artificial Intelligence*, vol. 94(1-2), pp. 1–6.
Carlton, D. and Perloff, J. 1990, *Modern Industrial Organization*, Scott Foresman, Illinois.
Chandler, S. 2000, 'Water trading – a new market to play', *Irrigation Australia*, vol. 15(1), pp. 4–10.
Demsetz, H. 1969, 'Information and efficiency: another viewpoint', *Journal of Law and Economics*, vol. 11, pp. 1–22.
Goulburn Murray Water 2000, 'Annual Report 1999/2000', Goulburn Murray Water, Tatura.
Goulburn Murray Water 2001, 'Northern Victorian water exchange results of trading for 2000–2001, Summary for Annual Report', Goulburn Murray Water, Tatura.
Green, J. 1977, 'The non-existence of informational equilibria', *Review of Economic Studies*, vol. 44, pp. 451–463.
Hafi, A., Klijn, N. and Kemp, A. 2001, *Efficient pricing and allocation of irrigation water – a model of the Murrumbidgee Irrigation Area*, 45th Annual Conference of the Australian Agricultural and Resource Economics Society, Adelaide, 23–25 January.
Hall, N., Poulter, D. and Curtotti, R. 1994, 'ABARE model of irrigation farming in the southern Murray–Darling Basin', *ABARE Research Report,* vol. 94(4), p. 3.
Hanley, N., Shogren, J. and White, B. 1997, *Environmental Economics in Theory and Practice*, MacMillan Press Ltd, Houndmills.
Harris, M. and Raviv, A. 1981, 'Allocation mechanisms and the design of auctions', *Econometrica*, vol. 49(6), pp. 1477–1499.
Hernandez Iglesias, C. and Lopez Paredes, A. 1999, 'Beyond experimental economics: trading institutions and multiagent systems', 5th International Conference of the Society for Computational Economics, Massachussetts, 24–26 June.
Holland, J. 1975, *Adaptation in Natural and Artificial Systems*, University of Michigan Press, Michigan.
Imagine That Inc 2000, Extend™ Professional Simulation Tools User's Guide, vol. 5, San Jose, California.
Kagel, J. and Levin, D. 2001, 'Behaviour in multi-unit demand auctions: experiments with uniform price and dynamic Vickrey auctions', *Econometrica*, vol. 69(2), pp. 413–454.
Mason, R. 2000, 'Network externalities and the coase conjecture', *European Economic Review*, vol. 44, pp. 1981–1992.
Montgomery, D. 1972, 'Markets in licences and efficient pollution control programs', *Journal of Economic Theory*, vol. 5, pp. 395–418.
Murray–Darling Basin Commission 1999a, *Salinity and drainage strategy – ten years on*, Murray–Darling Basin Commission, Canberra.
Murray–Darling Basin Commission 1999b, *The salinity audit of the Murray–Darling basin, a 100-year perspective*, Murray–Darling Basin Commission, Canberra.

Murray Irrigation 2001, *Water Exchange Summary*, [Online]. Avaliable: http://www.murrayirrigation.com.au/

New South Wales Department of Land and Water Conservation 1999, *Water trading development and monitoring, final report*, Marsden Jacob Associates, Camberwell.

Satterthwaite M. and Williams S. 1989, 'The rate of convergence to efficiency in the buyer's bid double auction as the market becomes large', *Review of Economic Studies*, vol. 56, pp. 477–498.

Smith, V. 1982, 'Microeconomic systems as an experimental science', *American Economic Review,* vol. 5, pp. 923–955.

Smith, V. 1987, 'Auctions', in Eatwell, J., Milgates, M. and Newman, P. *The New Palgrave: a Dictionary of Economics*, MacMillan Press Limited, London.

Vickrey, W. 1961, 'Counterspeculation, auctions and competitive sealed tenders', *Journal of Finance*, vol. 16, pp. 8–37.

Wilson, R. 1985, 'Incentive efficiency of double auctions', *Econometrica*, vol. 53, pp. 1101–1115.

Young, M., Macdonald, D., Stringer, R. and Bjornlund, H. 2000, *Inter-state water trading: a two-year review*, draft final report, CSIRO Land and Water, Adelaide, December.

Appendix

The basic form of the model is that used in Bell and Beare (2002). While the choice of functional form is ultimately arbitrary, the forms selected allow the exploration of a range of production possibilities and external impacts. A trade emulation algorithm was embedded in a larger agent-based simulation, implemented in EXTEND (Imagine That 2000) using a genetic algorithm (Holland 1975). The simulation model can be used to examine a range of economic instruments for resource management with an arbitrary spatial network of n agents. Each agent is represented by an independent profit maximising algorithm. Production dependencies are represented by the network connections. Externalities that arise through an agent's production process are passed sequentially along these connections.

The production function for an individual agent i is represented by a generalised quadratic function:

$$f_{it} = \mu_{it}\left(\alpha_{i1}x_{it} + \alpha_{i2}y_{it} - \alpha_{i3}x_{it}y_{it} - \alpha_{i4}x_{it}^2 - \alpha_{i5}y_{it}^2\right)$$
$$\mu_{it}, \alpha_{il} > 0 \;\; \forall\, i, t; \;\; l = 1 \text{ to } 5 \qquad (1)$$

where f_{it} is agent i's output at time t, x_{it} and y_{it} are inputs to production at time t, and μ_{it} and α_{il} are production function coefficients.

An externality E_{it} incurred by agent i is assumed to arise through the use of input x in production. Specifically, for any agent i:

$$E_{it} = \sum_{j \in J_i} \delta_j x_{jt} \qquad (2)$$

where J_i is the set of agents above agent i in the resource use network and δ_j is the proportion of agent j's usage of input x which is transferred as damage to production of agents lower in the network. The externality is assumed to have a non-linear impact on agent productivity such that:

$$\mu_{it} = \max\left[0, \mu_{i0} - \gamma_i E_{it}^2\right] \quad \text{for } 0 < \gamma_i < 1 \tag{3}$$

Individual agents act independently to choose x, y, the quantity and reserve price of entitlements offered for sale and the quantity and bid price of entitlements to purchase, to maximise expected profit π each period from production and entitlement trade. That is:

$$\pi_{it} = \pi_{\text{production}} + \pi_{\text{entitlements}} \tag{4}$$

for

$$\pi_{\text{production}} = pf_{it} - cx_{it} - dy_{it} \tag{5}$$

where p is the market price of output, and c and d are constant unit input costs. For an initial allocation of entitlements of w_i to agent i, if there is no central trader of entitlements then $\pi_{\text{entitlements}}$ is given by:

$$\pi_{\text{entitlements}} = \rho_t(z_{it} - v_{it}) \quad \text{for } x_{it} \leqslant w_i - z_{it} + v_{it} \tag{6}$$

where ρ is the traded entitlement price, v_{it} is the quantity of entitlements purchased by agent i and z_{it} is the quantity of entitlements from agent i's initial allocation which are sold. If there is a central seller of entitlements which is maximising revenue from entitlement sales, then agent i's profit from entitlement trade is given by:

$$\pi_{\text{entitlements}} = -\rho_t v_{it} + \left(\frac{w_i}{\sum_i w_i}\right)\rho_t \sum_i v_{it} \tag{7}$$

The first term of (7) is the cost of entitlement purchases and the second is agent i's share of revenue from entitlement sales by the central trader. Note that if all available entitlements are sold, revenue from entitlement sales received by agents is the same when there is a central trading house as when there is no central trading house. The values of parameters used to calibrate equations (1)–(7) are detailed in table 1. With this set of parameter values, the marginal cost function for resource damage is convex and the production function is concave. The model results were found to be robust to alternative parameterisations that preserve the concavity of the production function and the non-concavity of the marginal cost function. Sensitivity analysis results are available from the authors on request.

To emulate trade in water entitlements, a sealed bid auction framework was utilised in which entitlements are distributed to the highest bidding producers first until the entitlement market is cleared. Individual producers are assumed to be self-advancing, with each attempting to find their own optimal combination of inputs and entitlements. The agents are linked through market outcomes and through the production externality (equations 2 and 3).

Table 1 Model parameter values

Parameter	Value
α_1	20
α_2	20
α_3	0.025
α_4	0.05
α_5	0.05
μ_0	1
γ	0.000035
δ	0.5
p	1
c	1
d	1
Number of market trials k	400

Entitlement allocation under atomistic competition

Each agent engaged in trade has a set of potential trading strategies. Under atomistic competition, an individual agent's trading strategy consists of four non-negative elements: a quantity offered for sale, an associated reserve price on the quantity offered, a quantity bid for additional entitlements and a bid price. Agents are assumed to start with no information on the value of an entitlement, but learn through a series of market trials, to formulate a bid that will maximise their own expected net revenue. In each trial, agents submit their bid to the market. To evaluate a set of trading strategies, trades are executed from the highest to successively lower bid prices until the market is cleared. The market price is the marginal bid (the lowest bid price that is accepted). Given the entitlement outcome, agents calculate their net revenue from optimal use of entitlements in production, taking into account the impact of others on their own productivity, and use this information to revise their bid to the market in the following trial in an attempt to increase their net revenue (as in Bell and Beare 2002). This process of receiving bids and distributing entitlements is repeated and a new market price and sales revenue are determined. An agent's revenue is maximised when he is unable to locate an alternative bid strategy that improves his expected net revenue, given a range of possible bid strategies of other agents. The actual trade outcome is that which results from the market resolution of the set of agent's final bids.

Entitlement allocation with a trading house

In the operation of the market with a single seller, agents submit to the trading house bids for entitlements. These bids comprise a desired quantity of entitlements and a maximum price that the agent is willing to pay for this quantity. With a single seller, distribution of entitlements to agents is effectively conducted as a uniform price sealed bid auction.

In seeking to distribute entitlements between agents to maximise overall sales revenue, the trading house distributes entitlements to highest bidders first, and then the remaining bidders until no entitlements remain. The market price is the bid price of the last successful bidder. The trading house then calculates sales revenue as the market price multiplied by the quantity of entitlements distributed. Agents calculate their net revenue from optimal use of entitlements in production, taking into account the impact of others on their own productivity, and use this information to revise their bid to the market in the following trial in an attempt to increase their net revenue. This process of receiving bids and distributing entitlements is repeated and a new market price and sales revenue are determined. In the simulations reported in this paper, the process was repeated in a series of k random trials. During these trials, no actual trade takes place. The distribution of entitlements that results in the highest revenue to the trading house, given the profit maximising trade strategies of agents, is then taken as the actual trade outcome. Provided that each agent's bids strictly increase with their valuation of entitlements (and all agents are equally risk averse), the auction outcome will result in entitlements going to bidders with the highest valuations (Vickrey 1961; Kagel and Levin 2001).