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Transferable Water Entitlements
A Game Theory Approach

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This paper examines the social equity consequences of transferring water entitlements between representative farms in the Border Rivers Region of Queensland using a co-operative game thoery model.

As the Australian water economy enters a mature phase whereby the demand for water will exceed the available supply in many river basins, State governments are examining alternative water management policies, such as transferable water entitlements, which promote a efficient and equitable water distribution. It is foreseen that with the increasing relative scarcity of water, a more commercially competitive environment for water will grow in the future. Water co-operatives will play a dominate role in water economies. Water cooperatives are growing in number, it is conceivable that markets for instream water, in the long-term, will be dominated by the bargaining power of these cooperatives. In America, farmers have formed co-operatives for water security and compete with industry groups in water markets. Cooperative game theory is effective in analyzing concentrated markets were bargaining plays an important role.

The paper begins with a review of the Australian water economy. It then discusses the pressures for institutional change. The main part of the paper consists of a case study comparing alternative water allocation policies for the Border Rivers Region of Queensland. A game theory model is presented and used to estimate pareto-efficient and socially just payoffs from trade between six representative farms in the basin under alternative policy option.

An overview of the Australian water economy

The use of water resources in Australia began, as it did in England, under riparian common law. However, unlike in England, the climate of Australia made water a scarce resource, and water allocation became a critical issue for Australia's development. The riparian philosophy restricted a growing demand for water away from traditional water use throughout the 1800's, particularly during the gold mining boom. As a result, State governments enacted legislation to regulate and allocate instream water.

The demand for institutional change

With the growth in demand from both the agricultural and industrial sectors, the water economy in Australia had moved from an expansionary phase into the mature phase by the early 1980's. Randall (1980) described the expansionary phase as a period of an elastic supply of water, a low level of demand, little competition for water and minimal externalities. As the water economy develops a period of inelastic supply with greater competition for water between irrigators, and more serious externalities arises. Further, the possibility for expanding the supply becomes highly expensive.

While no distinct transition can be isolated between the expansionary and the mature phases, there was a number of distinct events in Australia during the 1980's which increased the demand for water. A severe drought during the early 1980's brought increasing competition for water into the political arena. Water was no longer viewed as a resource in infinite supply, and the goals of ensuring an efficient and equitable distribution superseded the goal of increasing the area under irrigation (Watson et. al., 1980; Verdich, 1986). Further, while the original allocations were designed to irrigate effectively crops deemed suitable at time of issue, cropping patterns and irrigation practices have changed dramatically over time. This has resulted in a less efficient water allocation.

Transferable water entitlements have been operating overseas for many years, particularly in America. The Australian State governments have recently looked towards transferability as a means of reallocating the available water resource.

A Case Study of the Border Rivers Region of Queensland

The catchment of the Border River Basin extends from the escarpment of the Great Dividing Range near Stanthorpe in the east to Mungindi in the west, an area with a mean runoff of 1000 gigalitres per year (Brown et. al., 1983). The system consists of three main rivers: the Dumaresq, Macintyre and Barwin. The use of instream water is regulated on the Dumaresq river between Bonshaw and Mungindi on the Barwin river, a distance of approximately 130 km.

This paper will evaluate four alternative allocation methods based upon the trade between six representative farms in the Border Rivers region. Performance of the policies is compared on the basis of distribution of incomes between farms.

The selection of representative farms

Representative farms have been selected on the basis of data supplied by the QWRC on the cropping patterns, location, size of water allocation and on-farm storage of the 112 licensees along the Queensland side of the regulated system for the 1985/86 and 1986/87 water years. The Border Rivers basin was divided spatially into three areas according to cropping and climatic characteristics, as follows:

Area 1: Glenlyon Dam to MacIntyre Brook, with a semi-arid climate and growing pasture, lucerne and cereal crops.
Area 2: MacIntyre Brook to Boomi Weir, with a warmer, arid climate and growing a variety of broadacre crops.
Area 3: Boomi Weir to Mungindi, with a arid climate and growing predominantly cotton.

Due to the limitations of the game theory approach, it was decided to confine the analysis to six representative farms. While the number of farms is too small to justify random sampling procedures, an attempt was made to ensure that selected farms were as representativa as possible.

Character... s of the representative farms

Profiles of the selected farms in terms of water allocation and cropping practice are presented in Table 1.

Table 1
Characteristics of the representative farms

Farm	Area	Nominal Water Allocation (ML)	Cropping
a	1	152	20 Ha of pasture
b	1	300	40 Ha of pasture 16 Ha of lucerne
c	2	40	Nil
d	2	1300	202 Ha of cotton
e	2	700	20 Ha of barley 81 Ha of pasture
f	3	3650*	405 Ha of cotton

* 3000 ML of on-farm storage utilize high flows. This is additional to allocation and charged at a lower rate.

Climatic data were collected from regional post offices along the river basin, and were used in conjunction with Department of Primary Industries evaporation figures to estimate crop water requirements. Crop gross margins for the crops grown were taken from a number of sources including Enterprise Budgets for the North West of N.S.W. by O'Sullivan (1985), and the Rural Advisory Service Gross margins Project of the National Australia Bank. Unfortunately, it is not possible from the available data to estimate farm incomes from dryland activities. While this is recognized as a limitation of the study, it is believed that the income generated from irrigated cropping would be representative of relative total farm income and so of irrigators' relative welfare. An assumption is that as the farmers have irrigation licenses, then the majority of farm income is derived from irrigation.

The policy options

Four alternative policy options for the definition of water entitlements in the Border Rivers region are investigated.

Option 1: maintain the traditional Queensland allocation of a percentage of nominal allocation. The traditional method has been included as a point of comparison.

Option 2: a two-part allocation similar to the New South Wales system. Based on the recommendations of the CWPR, the Part A allocation is taken as 150 ML (or full allocation), and the Part B allocation is proportion of the balance of the available water resource. A two-part system is seen from the water authorities viewpoint as balancing the risk of extremely low flows against higher announced allocations. In other words, each irrigator faces the risk of having a smaller allocation on average but has the assurance of at least the "A" allocation supply, i.e, 150 ML or, in the case of smaller allocations, the full nominal quantity.

When the total allocation is made on a proportional basis, those with smaller allocations may be faced with a non-viable supply; insufficient water for even domestic use and livestock proposes.

Option 3: a two-part allocation with consumptive use.[1] Consumptive-use implies defining a right to provision of water

1 The definition of consumptive use adopted here differs from the American definition. In America water rights could be maintained under a consumptive use definition without utilisation. The definition adopted here incorporates the Centre for Water Policy Research recommendation for the recoupment of unutilised water allocations.

according to some form of historical use. In other words, irrigators are only entitled the quantity of water to which they have made beneficial use in the past. Naturally, this includes the recoupment of unutilized allocation, but also involves some mechanism of redistribution of underutilized allocations to irrigators. Under this system redistribution of water as in Table 2 will occur. The total quantity of water available is 1886 ML. The quantity required to grow the crops in the representative farms totals 2196.9 ML. The Part A allocation is 643.6 ML (43.6 ML for farm a and 150 ML for the other farms), leaving 1242 ML for Part B allocations. Given a total Part B allocation of 1553.3 ML, the 1242 ML represents announced Part B allocations of 80% of this total. Since Farm c has no demand for water, the nominal allocation to Farm c is reallocated to other users.

Table 2

Redistribution under a two-part allocation after reallocation of unutilized and underutilized allocations

Irrigator (Player)	Nominal allocation ML	Historical use ML	Part A allocation ML	Part B allocation ML	New announced allocation ML
a	152	43.6	43.6	0.0	43.6
b	300	180.4	150.0	24.2	174.2
d	1300	1224.7	150.0	859.7	1009.7
e	700	234.7	150.0	67.8	217.8
f	3650	3513.3	150.0	290.6	3440.6
Total		2196.9	643.6	1242	1886.0

<u>Option 4</u>: traditional Queensland allocation with <u>consumptive-use</u>. The consumptive-use approach adopted here includes a proportional reallocation to irrigators who are utilizing their allocations. The redistribution is presented in Table 3. The consequence of such a policy means that farms d and f, which require more than the announced allocation to irrigate their crops efficiently, receive a larger allocation relative to that under traditional allocation. Likewise, those who require less than 60% of their nominal allocation will receive less under this consumptive-use definition of allocation.

Table 3

Traditional Queensland allocation with consumptive-use

Irrigator (Player)	Nominal allocation	Traditional allocation	Historical use	New announced allocation
a	152	91	43.67	37.5
b	300	180	180.36	154.7
c	40	24	0.00	0
d	1300	780	1224.73	1050.9
e	700	420	234.78	201.4
f	3650	3390	3513.38	3440.5
Total		1885	2196.93	1885.0

<u>The game theory model and theories of social justice</u>

In developing a water market policy, Randall (1980), among others, viewed the role of the market as being to promote an efficient and socially equitable water distribution. In evaluating equity, the social choice philosophies most frequently embraced by economists include the Rawlsian and Utilitarian (Benthamiate) theories of social justice.

Under the Rawlsian theory of social justice, the objective of society is to maximise the welfare of the worst off members of society. Rawls discusses the economy, and so the set of policies effecting society, as a social state. Suppose individuals in a social state are ordered in terms of their welfare such that 'i' is the ith position in a social state x and $w_i(x)$ is the welfare of individual i in social state x [2]. The Rawlsian lexicographical rule would argue that for a pair of social states x,y, it is true that x > y (i.e. social state x is preferred to social state y,) if and only if there is some individual j,$(1 \le j \le N)$, such that

$w_j(x) > w_j(y)$, and
$w_i(x) = w_i(y)$, for all $i < j$ (Sen, 1973, p. 234)

For example, assume a society consisted of 4 players and the possibility of two social states, x and y, and that some measure of their welfare in term of essential goods was possible and produced (2,3,4,7) in social state x and (2,3,5,6) in social state y. Applying the Rawlsian lexicographical rule, the two social states are equal up to person 3, where state x maximises the welfare of the worst, and so x > y.

In contrast, the common usage of the Benthamiate philosophy of utility would argue that the distribution of wealth within society must maximise the 'greatest happiness of the greatest number'. Hence, for any pair of social states x,y, it is true that x > y if and only if

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2 A variety of definitions of welfare could be chosen, but in the present context only the general concept is needed.

$$\sum_{i=1}^{N} w_i(x) \geq \sum_{i=1}^{N} w_i(y)$$

In the following section, these philosophies of social justice are incorporated into a game theory model.

The concepts of cooperative game theory

Game theory does not attempt to establish a unique equilibrium price. Rather, it attempts to estimate individuals' payoffs from coalitions in the light of their threat potential or bargaining power.

Suppose there are a number of farmers competing for allocations o: a scarce resource. These farmers may be regarded as players in a competitive market or 'game'. The complete set of players is N, where N = (*a,b,c,...*). In the process of trade, players will enter into agreements with a subset of N, say S. where S is known as a coalition.[3] For example, S=(a,b) is a coalition of farmers a and b. This means that farmers a and b enter into trade of water allocations. The payoff from trade is the increase in total farm income gross margin as a result of the new water quantities. The payoff from each potential coalition forms part of the characteristic function. The characteristic function provides a single numerical index of the potential worth of each coalition.

Naturally, not all possible coalitions are rational in the sense of increasing social welfare. Suppose the payoff to Player i prior to trade is given as v_i; the payoff to Player i when this Player is involved in trade of water entitlements is t_i; and the

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3 If there are N = 6 players as here, then possible coalitions are (a), (b),..(f), (a,b), (a,d),..(e,f),...(a,b,d,e,f) a total of 2^N-1 or 63 coalitions. Note that the definition of a coalition includes individuals acting in isolation. i.e., every player could become a coalition.

payoff to each coalition S is t_s. For the six farms, payoff vectors may be defined as

$(v_a, v_b, \ldots v_f)$ before trade, and
$(t_a, t_b, \ldots t_f)$ after trade.

For a coalition to be rational:

1. The payoff from trade to each individual must be at least equal to the payoff to the individual if he or she did not enter into trade; i.e. the payoff prior to trade. This may be expressed algebraically as,

$$t_i \geq v_i, \; i \in N \qquad \ldots\ldots(1)$$

2. The sum of the payoffs to members of a coalition S is at least equal to the payoff to the coalition S.

$$\sum_{i \in S,} t_i \geq v_s \; S \subset N \qquad \ldots\ldots(2)$$

3. The sum of the payoffs to individuals equals the payoff from a grand coalition of all the players. In other words, for a coalition to be rational, it must be at least as profitable as the grand coalition.

$$\sum_{i=1}^{N} t_i = t_N \qquad \ldots\ldots(3)$$

The payoff vectors which fulfil conditions (1), (2), and (3) are known as undominated imputations, and constitute the extreme points of what is known as the core. The core is the set of imputations in which every Player finds trade rational. Each Player receives at least as much as he or she would receive without trade, and no trade agreements outside the core would provide any greater payoff than is attainable from a coalition of all the players. The core contains all the payoff vectors for pareto-efficient distributions; if a game does not have a core then it is not possible to achieve a Pareto-efficient distribution of the available water resource from the market.

The worth of a coalition and the payoff to individual players, becomes the basis from which bargaining commences in the market. In other words, the bargaining arena (the core) is bound by the values of coalitions and the value of all the irrigators joining a grand coalition. The bargaining power or threat of a Player can be demonstrated using a simple example. Assume Player a has two options, to trade with Players b and c, or trade with Player d. If, as a result of trading with Player d, the combined income of players a and d increases by, say, $1000, then potentially Player a could increase his or her income by up to $1000. Player a could then use the potential income from trade with Player d as a bargaining tool or threat in negotiations with Player b and c to ensure at least $1000.

The set of undominated imputations which forms the core is often too large to provide any worthwhile information. As a result, theorists have examined alternative means of contracting the core to a unique solution.[4] One option not yet explored, to the best of the authors' knowledge is identifying socially just imputations within the core. The next section will demonstrate how Atkinson's measure of economic inequality can be incorporated into a game theory model to estimate socially just imputations within the core.

Atkinson's Measure of Economic Inequality

Atkinson (1970) in examining measurement of inequality, proposed what he called 'the equally distributed equivalent income'. He defines this as the level of *per capita* income equal to the total welfare generated by the actual income distribution

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4 Two of the more commonly used criteria for identifying unique solutions within the core are the Shapley value and the Nucleolus (Friedman, 1986; Basharach, 1976; Owen, 1968). These criteria are not, however, designed to identify socially-just imputations.

(Atkinson, 1970, Sen, 1973). The equally-distributed equivalent income y_e varies according to the degree of inequality in society (α) such that

$$y_e = \sum_{i=1}^{N} \frac{(yi)^{1-\alpha}}{1-\alpha}$$

where y_i is the income of individual i

α is a weighting of the distribution of income in society.

Broadway and Bruce (1983) examined the specific values of 'α' to achieve the objectives of Rawls and Bentham These are summarized in the Table 4.

Table 4
Alternative values of 'α' in the Atkinson utility function

Value of 'α'	Social welfare function
α -> 0	Benthamiate welfare contour
α -> infinity	Rawlsian solution

<u>Mathematical Programming Formulation of the Game Theory Model</u>

In the present discussion the measure of welfare of individual i is the payoff after trade t_i. A model which maximizes a wieghted sum of farm payoffs π_N, subject to the constraints of the core, will identify imputations which are both pareto-efficient and socially equitable according to the criteria implied by the objective function. That is, the model may be formulated as,

$$\max W_N = \sum_{i=1}^{N} \frac{t_i^{1-\alpha}}{1-\alpha}$$

subject to core condition constraints of

$t_i \geq v_i, \quad i \in N$ (individual rationality)

$\sum_{i \in s} t_i \geq v_s, \quad s \subset N$ (group rationality)

$\sum_{i=1}^{N} t_i = t_N$ (superadditivity)

While a fusion of game theoretic philosophies and axioms of social justice theoretically provides a model for evaluating the performance of a water management policy, the real test comes when it is applied to a case study. The empirical example which follows applies the game theory approach to the market for instream water in the Border Rivers Basin of Queensland.

The application of the model

Applying the model involves estimating the potential income of each of the coalitions from among the six players selected from the Border Rivers Basin. Socially-just imputations are then derived from the set of imputations which provide a rational incentive for partial coalitions to trade, i.e. from the core.

A linear programming model is used to estimate the maximum income which could be generated from the available water resource in each possible coalition under each method of allocation. The optimal payoffs to each of the coalitions form the constraints of the game theory model.

The core and final imputations for each policy option have been derived using QSB and Gams/Minos programming packages and presented in table 5. Table 5 presents the income to each of the players, from Player a to Player f, and the payoff to the grand coalition for each policy option, i.e. N_{tp} is the payoff to the grand coalition under a two-part method of allocation.

The optimal plans derived by programming indicate that the definition of the water entitlement before trade, and the most equitable distribution post-trade, depend upon the philosophy of social justice adopted, viz. whether the government adopted a Rawlsian or Bentham philosophy of justice, whether the welfare of non-irrigators is relevant in evaluating the equity of market solutions.

As expected, reallocating the resource under a consumptive-use criterion increases the pre-trade return from the water resource. Under a two-part definition the average farm income derived from a consumptive-use distribution is \$108365, compared to \$102738 from the traditional allocation.

A Rawlsian evaluation of the payoffs

The relative justice between the two-part allocation and the Queensland allocation in terms of a Rawlsian criterion depends upon whether the allocations are incorporated with a consumptive-use or just a traditional allocation definition. In terms of consumptive-use and excluding ties, the lowest payoff of the two-part definition exceeds the lowest payoff of the Queensland definition on both a pre-trade (\$4633 compared to \$4434) and post trade (\$5042 compared to \$4758). However, under the traditional method of allocation, the Queensland definition has a greater minimum payoff than the two-part method, both pre-trade (\$164733 compared to \$155809), and post-trade (\$1705 compared to \$1613).

The 'most equitable' distribution also depends upon the perceived welfare of those players who do not use their allocation. If the level of income from irrigation is to be used as a relative measure for the players' incomes, then Player c, having no income generated from irrigation, would be seen as the worst off. However, Player c may also derive income from other sources than from irrigation. As a result, his or she welfare could be considerably higher than that reflected in his or her income from irrigation.

If Player c is excluded from any judgement as to the equitable distribution of the resource because his or her income is unknown, then, under a Rawlsian criterion, a traditional definition produces a more equitable post-trade distribution of the water resource than allowing trade in terms of consumptive-use allocations (8231 compared to 5042, and 7860 compared to 4758).

The choice between the two-part allocation and the Queensland method (under a Rawlsian criteria of justice) becomes a question of the perceived potential of the market to promote the welfare of the worst-off. The two-part allocation produces a more equitable distribution of the resource than the traditional method post-trade. However, pre-trade, the traditional method produces a more equitable initial distribution of the resource. Hence, the two-part allocation method relies more heavily upon the market processes to produce an equitable distribution of the resource.

<u>A Bethamiate evaluation of the Payoffs</u>

Under a Benthamiate philosophy of justice, assuming an objective of promoting the greatest happiness of the greatest number, the consumptive use method of allocation produces a more equitable water allocation under both the two-part method and the

Queensland allocation than the more traditional method pre-trade.

Yet, surprisingly, the income generated from the water distribution under a two-part system of allocation pre-trade is less than that generated under the Queensland definition for both the consumptive use criterion and the traditional water allocation method. The total income generated prior to trade for the two-part allocation under consumptive-use equalled $650194, compared to $652720 under the traditional allocation. Likewise the total income generated under the Queensland definition ($625822) exceeds the income generated under a two-part method of allocation ($616428). Hence, a two-part method would produce a less efficient allocation of the resource if it were not complemented with a policy allowing transferability. Intuitively, one would have suspected that given the possibly inefficient allocation of the resource, the traditional method would be less efficient, than a system based on a reallocation and a two-part allocation. Hence, to promote the greatest happiness of the greatest number pre-trade, the QWRC should maintain the Queensland method of allocation and redistribute the available resources on a consumptive use basis.

Conclusion

A game theory approach provides some insight into policy options in the management of water resources. In essence, the appropriate allocation and definition of the tradeable commodity for the Border Rivers region depends upon society's philosophy of equity. If the goal of society is to maximise the welfare of the worst off then further study is needed into the welfare of licensees not utilising their allocations. If the welfare of non-irrigators is not considered, and there is confidence that the market will be effective in redistributing the available water resource, then the QWRC could adopt a consumptive-use definition using a two-part allocation method similar to that used in New South Wales. If however, the lack of irrigation income is a reflection of the welfare of non-irrigators, then to promote the welfare of the worst-off the traditional method of allocation and Queensland allocation method should be maintained.

Alternatively, if society is to aim for the greatest happiness of the greatest number then the government can achieve this by maintaining the current method of allocation and redustribute unutilised allocations.

What is clear from both the Rawlsian and Benthamiate solution is that if a socially-just and efficient distribution of the resource is to be achieved there needs to be a competitive awareness of the potential bargaining power each water user possesses. The performance of the market has a significant effect upon the distribution of the water resource, and so the social justice of alternative methods of allocation. Further, ensuring an 'equitable' distribution of the available water resource depends upon the institutions view of its aims in terms of social justice.

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