The equity implications of alternative water pricing policies

by

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Introduction

While instream water is a naturally occurring resource, water authorities incur costs in storing and managing the distribution of the water. To cover these costs irrigators and other users are charged for the supply of water. In the past, the distribution of the charges were determined by the Water Authorities' pricing policy. With the introduction of transferable water entitlements, the final distribution of water charges, and income derived from the water resource will in part, be determined by market forces[1].

In developing a water policy, common property writers, such as Randall (1980), view the role of regulating institutions as promoting an efficient and socially just distribution of the available resource. The objective of this paper is to evaluate alternative water pricing regimes in terms of their effect on the distribution of income derived from water entitlements in a market environment. The paper will assess the distributional consequences of trade under three pricing mechanisms across four methods of water allocation. The payoff vectors from trade will depend upon bargaining between irrigators. To incorporate the bargaining process, a number of gaming equilibria are used to estimate potential payoff vectors from trade.

Alternative water pricing regimes

To date, there have been two main methods of water pricing in Australia, two-part and simple volumetric pricing. Both these methods are based upon on a cost approach to water charging. An alternative approach is to charge according to the benefits derived from the water resource. Each of these pricing policy mechanisms will be briefly explained.

Simple volumetric pricing

A simple volumetric charge, as the name suggests, involves charging for each unit (megalitre) of water consumed. The charge per unit tends to be constant provided the consumption is within the water allocation. While such a system of pricing is administratively simple, it has been questioned whether a volumetric

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[1] While water markets in Queensland are in their infancy, they could become an important redistribution mechanism in the future.

pricing policy will promote efficiency. Griffin and Perry (1985), for example, argue that a volumetric pricing regime in isolation will not provide incentive to limit water consumption, irrespective of the price charged. Surely though, a very high charge would limit water use. To promote efficiency, Doppler (1977) argues for a combined volumetric (per unit consumed) and fixed water price.

In terms of being seen as equitable, a volumetric pricing system is based upon a "same price for same service" philosophy, and so promotes an individualistic view of equity. Australia is seen as a society which aims at promoting the "greatest happiness of the greatest number" and so would support a single unit charge for water. Whether volumetric pricing promotes distributive equity (relative to other possible pricing methods,such as two-part and benefit pricing), and other criteria of social justice is an issue which may be subjected to empirical analysis.

Two-part pricing

Two-part pricing involves charging each potential water user a minimum fee irrespective of whether water is used or not, and a constant price per megalitre of water consumed. Such a policy may not be seen as "equitable" as it imposes a fixed cost on irrigators irrespective of use.

Benefit pricing

Cost of supply approaches to water pricing, such as volumetric or two-part pricing, while useful in recovering capital and recurrent costs, or some proportion of them, do not consider income distribution of users. An alternative to cost-based pricing is to base the charge according to the benefit received from the water allocation. Benefit pricing, as the name suggests, is based upon the value of the final production. The charge could be a set percentage of the total gross margin of an irrigated crop or the differential between dryland and irrigated gross margins.

Carruthers and Clark (1981, p. 189) argue that if the benefit approach is used, it is advisable to charge according to a proportion of the incremental benefits from irrigation (net revenue with irrigation less net revenue without irrigation) and not solely on the gross revenue from irrigated agriculture. If equality of incomes is a policy objective, benefit approach to pricing based upon an adjustable charge, proportional to the benefit derived from irrigation, could be utilised.

Seagraves and Easter (1983, p. 670) argue against benefit pricing, claiming that "a common fallacy in the literature on irrigation pricing is a recommendation that prices be based on benefits. This means that users of the same water supply will pay different prices." Is this fair or equitable? Seagraves and Easter (1983) argue such a policy could be seen by users as 'downright unfair'. Further, they argue that such a policy would be too complex to be commonly acceptable and the pricing schedules would be difficult to estimate.

While a general discussion of the distributive consequences of alternative pricing mechanisms is useful in establishing the effect of the initial distribution of the costs (or part there of) associated with the resource, sight should not be lost of the fact that water allocations, and therefore the costs and revenue associated with water allocations, are now subject to market forces. The final distribution of water charges and the income derived from the resource, will depend upon the bargaining environment of the market. Game theory has been shown to be a useful tool in modelling the process of bargaining, and can incorporate formally defined theories of social justice.

The model

Suppose there are a number of individual farmers are competing for allocations of a scarce water resource. These farmers may be regarded as players in a competitive market or "game". The complete set of players is N, where N = {*1,2,3,..n*}. In the process of trade, groups of players will enter into agreements. A group of S players, where S is a subset on N, is known as a coalition[2]. If there are n players, the number of possible coalitions is 2^n. In order to keep the algebra in this study to a manageable size, the market has been limited to six players, for which a total of 2^6 or 64 coalitions is possible[3].

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2. Sometimes the term partial coalition is used for groups of only some of the players and the term super coalition is used for all players.

3. For any coalition, Player 1 could be either a member or a non-member. For each of these two possibilities, Player 2 in turn could be a member or non-member. For each of these four possibilities , Player 3 could be either a member or a non-member. In general, 2^n-1 arrangements are possible if the null coalition is excluded.

The expression v(S) will be used to represent the aggregate payoff to members of a coalition S. The payoffs to individual players acting in isolation may be represented as v({1}), v({2}), ... v({n}).

A "solution" to a game is a vector of the payoffs received by each player. This payoff vector or reward vector may be written $x = \{x_1, x_2, x_3, \ldots x_n\}$. A number of solution concepts or methods of deriving a reward vector are possible.

The most commonly used solution concept is the core. The core is the set of pareto-efficient imputations or reward vectors which are not dominated by other imputations. For a payoff vector to be in the core, and hence a reasonable candidate for a solution, it must meet the conditions of individual rationality, group rationality and joint efficiency. In essence, the set of core reward vectors satisfy the following conditions[4]:

$$x_i \geq v(\{i\}) \quad \text{for all } i \geq N \quad \ldots \quad (1)$$

$$\sum_{i \varepsilon S} x_i \geq v(S) \qquad (2)$$

$$\sum_{i=1}^{n} x_i = v(N) \qquad (3)$$

The set of reward vectors which form the core is often too large to provide any usable information. As a result, theorists have examined alternative means of contracting the core to a unique solution. One of these unique solutions is the nucleolus.

The nucleolus

The nucleolus is the reward vector whose excesses for all coalitions are as small as possible. By excess we mean the amount by which the worth of a coalition exceeds the receipts of its members in isolation. The nucleolus is estimated by a series of linear programs which reduce the core to the point where the maximum excess has a constant value throughout the set and any further reduction would obliterate the core. The process of estimating the nucleolus begins with contracting the core to the "least core". The "least core" is found by

4. For a more detailed outline of these axioms, see, Owen (1968), Shubick (1982, 1984).and Friedman (1991).

Minimising $v(S) - \sum_{i \varepsilon S} x_i$

If (e) is the excess, then the nucleolus is found by:

$$\text{Minimizing } e \qquad \ldots\ldots \qquad (4)$$

subject to

$$x_i + e \geq v(\{i\}) \text{ for all } i \varepsilon N$$

$$\sum_{i \varepsilon S} x_i + e \geq v(S)$$

$$\sum_{i=1}^{N} x_i = v(N)$$

To estimate the nucleolus the set of coalitions whose excess equal (e) are put aside and the next-largest excess is estimated. This process is repeated until no coalitions remain[5]. If the core is convex, the procedure will result in a unique reward vector corresponding to the lexicographic centre of the core; a minimax solution.

A Rawlsian approach

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 (Benthamite) theories of social justice.

This paper concentrates on the Rawlsian theory of social justice[6]. Under the Rawlsian theory of social justice, the objective of society is to maximise the welfare of the worst off members of society. Rawls (1971) discusses the economy, and so

5. For a more detailed explianation of the nucleolus see Scheidler (1969), Maschler et. al., (1979) and Wang (1988).

6. As transferable utility is assumed, all imputations within the core are optimal under a utilitarian criterion of social justice. To estimate a unique payoff vector under a Benthamite criteria of social justice would require a comparison of individual utility functions.

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 x_i is the welfare is the welfare of individual i in this social state[7]. 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,($1 \leq j \leq n$), such that

$x_j > y_j$, and
$x_i = y_i$, for all $i < j$ (Sen, 1973, p. 234)

A mathematically tractable approach to obtaining a Rawlsian solution is to maximise

$$\sum_{i=1}^{n} \log(x_i) \quad \ldots\ldots\ldots \quad (5)$$

subject to core condition constraints.

Applying alternative pricing methods in the Border Rivers region

As an empirical example of how game theory can be utilised in water management decision making, six representative farms from the Border Rivers region of Queensland have been selected. The characteristics of the farms are presented in Table 1. The current pricing policy in the Border Rivers region is a simple volumetric charge for instream water[8] . The instream water is divided into regulated and unregulated flows[9] and are charged under different schedules. The charges adopted in the paper are \$1.50 and \$7.40 for unregulated and regulated water respectfully[10].

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

[8] This has not always been the case, in fact the pricing of regulated water in the Border Rivers Region has gone though a period of change.

"Until 1985/86, the announced allocation was 100 per cent of the nominal allocation, and irrigators had to pay a minimum charge of 75 per cent of their allocations, whether used or not. In 1986/87, this was changed to a charging policy whereby irrigators paid only for what they used. In 1987/88, this was again modified so that irrigators paid a minimum charge equal to the cost of the initial announced allocation (55 per cent)" (CWPR, 1988, p. 50)

[9]Unregulated flow results from unexpected high flows in the river system.

[10] The charge of \$1.50 for unregulated water is only for the first 500Ml. Unregualated flow consumption above 500Ml is assumed to be free of charge.

Table 1

Characteristics of Representative Farms

Farm	Land Use	Area	Single Volumetric Allocation*
1	Pasture	40	91.2
2	pasture/	40	180
	lucerne	16	
3	nil	0	24
4	Cotton	202	780
5	Pasture/	81	420
	Barley	20	
6	Cotton	405	(3)390

* based on 60% announced allocation.

The regulated charge of $7.40 Ml, given 1885.2Ml available for consumption by the six irrigators, represents a total revenue for the Water Authority of $13,950. If a two-part pricing policy was introduced with a fixed charge of 75% of announced allocation, the same revenue ($13,950) would be achieved from a fixed cost charge of $10,462 (75% of 13950), and a variable charge of $1.85 Ml if all the water is utilised ($10,462 + $1.85 x 1885.2). The fixed charge for Player 1, for example, would equal 75% of his announced allocation, viz. under a single volumetric entitlement this would equal $ 506.16 (91.2ML x $7.40 x 0.75). Similar calculations were performed for each Farm under each method of allocation. The water charges under such a two-part pricing policy for each of the representative farms are presented in Table 2.

Table 2

Two-part pricing charges for each method of allocation

Player	Up-front charge ($)				Variable Charge
	Simple Volumetric		AB Allocation		
	Cons.Use	Trad.	Cons.Use	Trad.	($/ML)
1	207.95	506.16	241.98	837.66	1.85
2	858.92	999.00	967.37	1220.17	1.85
3	0.00	133.20	0.00	222.00	1.85
4	5832.71	4329.00	5600.78	3804.47	1.85
5	1118.10	2331.00	1208.29	2253.91	1.85
6	2444.94	2164.50	2444.44	2124.65	1.85

Finally if benefit pricing was introduced it may be based upon the difference in gross margins resulting from irrigation, weighted according to the area of land under irrigaiion for each crop type[11]. As an example, the water charge for irrigating crop (i) could be calculated as,

$$\text{water charge}_i = \frac{(\text{dryland}_i - \text{irrigated}_i)(\text{total revenue})}{\Sigma\ \text{crop area}_i(\text{dryland}_i - \text{irrigated}_i)}$$

where

crop area_i is the area planted to crop_i
dryland_i is the gross margin for dryland crop_i
irrigated_i is the gross margin for irrigated crop_i.
total revenue is the total revenue required by the water authority.

Table 3 summarises the calculation of adjusted gross margins for the single volumetric method of allocation. For example, for lucerne the difference in gross margins between irrigated and dryland farming is $877. In total 16 hectares of lucerne are grown. The weighted water charge for growing one hectare of lucerne amounted to $91.77, and the adjusted gross margin is $885.02.

Given the adjusted gross margins and front-up charges associated with the alternative methods of water pricing, the payoff vectors from trade were estimated using the game theory models.

11. More complex methods of benefit pricing have been proposed. Carathers and Clark (1981), for example, suggests determining the minimum acceptable income level, and then the proportion of benefits attributable to irrigation is taxable.

Table 3
Benefit pricing under the single volumetric method of allocation.

Crop Code	Area (Ha)	Gross Margins ($/Ha) Dryland	Gross Margins ($/Ha) Irrigated	Difference in Gross Margin ($/Ha)	Water Charge ($/Ml)	Adjusted Gross Margin
pasture1	58.85	161.61	247.82	86.21	9.021	238.79
pasture2	81.00	161.61	244.19	82.58	8.641	235.54
lucerne	16.00	99.80	976.79	876.99	91.770	885.02
cotton1	128.65	452.54	1067.18	614.64	64.317	1002.38
barley	20.00	91.20	180.75	89.55	9.3707	171.38
cotton2	44.96	453.54	1045.50	592.96	62.049	983.45

Results

Estimating the equilibrium of each game was done in two stages. First, the potential payoff to each coalition was estimated, then the game proper was solved using the payoff to the coalitions as constraints in each game.

A Linear programming model was developed for each coalition of farmers under each pricing policy and method of allocation. The Linear programming models took into consideration the water requirements of the crops grown, the area of irrigable land, water allocation, and evaporation and rainfall of the district. The incomes presented considered in the analysis are based solely on the revenue generated from the irrigable land available to the farms. Other farm enterprises are not taken into consideration. It is assumed that irrigation farming constitutes the main sourse of income for the farmers.

The estimated payoffs to the coalitions were used as constraints in the gaming models. A summary of results is presented in Table 4. In evaluating the distribution of income derived from alternative pricing regimes in a market environment, two criteria have been used. One method took the initial income of the farmers as given and assessed the distribution of the additional income derived from trade. The nucleolus exicographically orders the "excesses" farmers receive above

Table 4
Summary of payoff vectors after trade

Method of allocation		Pricing Regime Two-part pricing						
		Farm	1	2	3	4	5	6
	Cons.use	Nucleolus	4812	24376	0	199829	22362	416179
AB		Rawlsian	4995	25259	0	194270	27732	415300
Allocation	Traditional	Nucleolus	9585	26932	1430	187933	28492	413184
		Rawlsian	11062	28356	1539	175420	39473	411710
	Cons.use	Nucleolus	4534	23653	0	196819	26352	416198
Single		Rawlsian	4615	24302	0	196470	26722	415450
Allocation	Traditional	Nucleolus	6757	24772	687	187931	33159	414250
		Rawlsian	7441	25352	768	180250	40339	413400

Method of allocation		Pricing Regime Simple Volumetric pricing						
		farm	1	2	3	4	5	6
	Cons.use	Nucleolus	5048	25440	0	198710	23252	415100
AB		Rawlsian	5048	25440	0	193460	28501	415100
Allocation	Traditional	Nucleolus	11525	28799	1575	185130	29285	411240
		Rawlsian	11525	28799	1575	173280	41136	411240
	Cons.use	Nucleolus	4639	24437	0	20[illegible]510	22684	415280
Single		Rawlsian	4639	24437	0	195780	27414	415280
Allocation	Traditional	Nucleolus	6396	24434	768	181170	40218	414570
		Rawlsian	7495	25382	769	178530	42067	413310

Method of allocation		Pricing Regime Benefit pricing						
		farm	1	2	3	4	5	6
	Cons.use	Nucleolus	5105	24481	0	194590	25623	339100
AB		Rawlsian	5121	24881	0	192320	27878	398700
Allocation	Traditional	Nucleolus	9803	26188	1529	179130	32066	390410
		Rawlsian	11049	27389	1618	170980	38936	389170
	Cons.use	Nucleolus	4673	23523	0	198480	23114	399650
Single		Rawlsian	4743	23914	0	194720	26885	399170
Allocation	Traditional	Nucleolus	6988	24212	779	183210	33739	393340
		Rawlsian	7590	24726	848	176580	40015	392600

the income the can achieve without trade. The alternative is to lexicographically order the total income of the farmers, which I have here called the "Rawlsian approach".

Overall, the "optimal" pricing schedule in promoting the worst-off farmer is to adopt a benefit pricing schedule irrespective of the method of allocation. The worst-off is defined as the farmer with the lowest level of income. The "best" the worst-off can expect from a benefit pricing policy is $1618 under a benefit pricing regime compared to $1539 and $1575 from the two-part and simple volumetric pricing respectfully. Drawing broad conclusions from these results however, is questionable, as the differences are small and the judgements are based upon the payoff to a farmer who does not utilise his or her allocation. Furthermore, benefit pricing could also been questioned as a suitable pricing regime for a market environment.

While the income of the worst-off irrigator is maximised by adopting a benefit pricing policy, the process of trade changes the cropping patterns of the farmers. As a result, the revenue collected by the water authority also varies. The total payoff to the farmers under the two-part and simple volumetric pricing regimes is $667,556. Under a benefit pricing policy, the payoff to the farmers varies from $639,142 to $649,432 depending upon the method of allocation. In all cases the water authority collects more revenue than originally planned. Under AB (traditional) method of allocation. benefit pricing, based upon initial cropping patterns, produces an increase in water authority revenue of $28,414 ($667,556 less $639,142). In essence, the major limitation of benefit pricing, and water pricing policies based upon crop production in general, is the uncertainty of revenue to the water authority due to market reallocation of water resulting in a restructuring of cropping patterns. To reduce uncertainty of administrative revenue, the structure of agricultural production would need to be highly regulated.

If benefit pricing is rejected as a valid method of pricing, then the choice is between two-part pricing and simple volumetric pricing. It was found that for a simple volumetric pricing schedule the income of the worst-off farmer was at least equal to, if not above, the income of the worst-off under a two-part pricing regime, irrespective of the method of initial allocation. For example, under an AB (traditional) method of allocation, the payoff to the worst-off is $1539 if a two-part pricing schedule is used, compared to $1575 under a single volumetric price regime.

Making policy decisions on the basis of the distribution of income derived from the sale of unutilised allocations could also be questioned. If a farmer has an allocation of water and makes no attempt to utilise this allocation, should a farmer have the right to the benefits of sale of the allocation? Further, if a farmer are not generating income from their allocation, their allocation is clearly not a good reflection of their welfare, and so should be excluded. Player 3 could be excluded in two ways. The simplest way is to simply ignore the income derived from player 3, the second is to only consider consumptive use results, in which player 3 looses the right to their allocation.

If the first option is adopted, the "optimal" policy is to charge a simple volumetric charge, irrespective of the method of allocation except if an AB (traditional) method of allocation is used, in which case a benefit pricing schedule will achieve the optimal welfare of the worst-off. Alternatively, if a consumptive use option is adopted, then the benefit pricing policy could be adopted. If the benefit pricing policy is rejected, then a simple volumetric pricing policy could be adopted in preference to a two-part pricing policy.

Interestingly enough, if income player 3 is ignored, the welfare of the worst-off is maximised only if farm 3 is a player in the market. In other words it is better to allow farm 3 to keep the benefits he or her receives from trade as it maximises the welfare of the worst-off farmer who utilises his or her allocation. If farm 3's income is ignored, then the income of the next worst-off irrigator is maximised using a traditional method of allocation. For two-part pricing, for example, the worst-off under the traditional AB method of allocation is $11,062, compared to $4,995 under consumptive use, and likewise for the single volumetric pricing the lowest income is $11,525 under a traditional method of allocation,compared to $5,048.

Consistent throughout the analysis, the AB (traditional) method of water allocation produces the highest payoff to the worst-off farmer. The maximum payoff to the worst-off under a two-part pricing regime is $1,539 and $11,062, under a simple volumetric pricing regime, $1,575 and $11,525, and if benefit pricing is adopted, $1,618 and $11,049.

The conclusions drawn from the Rawlsian payoff vectors are consistent with the nucleolus payoff vectors. In other words the different reference point for assessing the distribution of income did not produce significantly inconsistent results.

Concluding comments

Gaming equilibria have been used to assess alternative pricing regimes across four methods of water allocation to determine which method of water pricing in a market environment will maximise the income of the worst-off irrigator and whether the result depends upon the method of allocation.

In summary, while the benefit pricing regime maximises the income of worst-off irrigator across all four methods of water allocation, it leads to uncertainty in terms of revenue for the water authority and water users. If the benefit pricing regime is rejected, the income of the worst-off irrigator is higher under a simple volumetric method of pricing than under a two-part pricing regime, irrespective of the method of water entitlement allocation. In essence, the method of allocation did not change the relative merits of the water pricing regimes however, the AB method of allocation produced the maximum payoff to the worst-off irrigator across all pricing regimes. The optimal policy for the water authority, if it was to maximise the welfare of the worst off farmer is to adopt a AB (traditional) allocation method and a single volumetric pricing policy.

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