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Water markets in Australia: an experimental analysis of alternative market mechanisms

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Formal water markets in Australia began as uniform price open call markets. As water markets in Australia continue to expand and mature, water managers are introducing double auction water markets, believing that such markets will produce more efficient outcomes. It is therefore timely and policy relevant to explore the relative merits of the two auction mechanisms in context. To date, experimental comparisons of these auction mechanisms have been based on balanced, single unit designs with defined buyers and sellers. However, many resource markets involve trade in multiple unit, often thin, double auction markets. This paper questions whether a multiple unit double auction performs as well as the more traditional open multiple unit call auction in a series of thin water market experiments.

Key words: auction theory, water market.

1. Introduction

In 1993, the Council of Australian Governments (COAG) introduced a raft of water reforms that included breaking the nexus between land and water. After some reservations by farmers to see their water entitlement as a tradeable chattel (Tisdell and Ward 2003), there has been growing interest in trading water entitlements. Mechanisms for trade have developed from simple bilateral trades between water entitlement holders in the same location to regional call markets and national exchanges. In 2004, COAG established a National Water Commission, and an associated National Water Initiative (NWI), to promote more efficient use of water and expansion of water trading. There are now eight main principal mechanisms for trading water in Australia, including the original call market, 'watermove' operated by the Goulburn-Murray Water Authority, various posted markets in Victoria, NSW and SA, and the National Stock Exchange of Australia market 'waterexchange' – allowing interstate trade in allocations and forward contracts (National Water Commission 2009). The volume of trade is increasing rapidly with over 1.7 million ML traded in the southern connected Murray-Darling Basin systems in 2008–2009 (National Water Commission 2009, p. 34).

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Given the size and growing importance of water markets in Australia, it is timely to implement well-crafted market institutions.[1] State and Federal agencies are constantly monitoring and evaluating the performance of these markets. These agencies need information on the relative performance of different auction structures to form future water trading policy. Along with field observations, policy options can be tested under laboratory conditions. Analysis in an experimental economics laboratory allows policy makers the opportunity to rapidly assess alternatives under controlled conditions. Tisdell *et al*. (2004, p. 1) argue that the laboratory provides 'a formalised, replicable approach to rapidly assess alternate policy directives, typically expressed as market outcomes, prior to catchment-wide implementation'. They also argue that '[w]ell-designed experiments allow for the evaluation of participant willingness to exchange, the stability of diverse institutional structures across an array of market conditions, and the efficacy of policy directives and highlight potential detrimental outcomes, which may compromise a water reform process' (Tisdell *et al*. 2004, p. 1). Murphy *et al*. (2000) point out that institutional change in water management needs to be adaptive and cautious as irreversibility makes untested policy decisions costly to society. The laboratory allows policies to be tested under controlled conditions prior to field trials.

Given this context, this paper reports the results of a series of economic experiments comparing the relative performance of the more traditional open call market used in Victoria for many years with a multiple unit double auction market conducted under controlled conditions. The paper begins with a brief description of the two auction structures and an overview of literature comparing them. This is followed by the research questions and experimental designs used in this study. The experimental outcomes are evaluated in terms of market activity, convergence and allocative efficiency. The paper concludes with a summary of findings and recommendations for further research.

2. Call and double auction markets

We begin with a brief description of the open call and multiple unit double auction mechanisms. An open call market involves potential traders (buyers and sellers) submitting sealed offers to a central agency or auction house within a prescribed time. Once the prescribed time has elapsed, the market is 'called'. Trades are executed by the clearing house.[2] The authority orders the buy offers from the highest price to the lowest and the sell offers from lowest to highest. In the case studied here trade occurs at a uniform price. The

[1] The maturing nature of Australia's water economy was first documented by Randall (1981).

[2] In the case studied here the water authority acts as the clearing house (as it does in Victoria).

authority notifies successful traders and releases the market price and volume traded information only. In an open call, all the bids and offers are made public once all the trades are completed (see Smith *et al.* 1982; Cason and Friedman 1996). This call design is similar to that used in the Goulburn Broken catchment for many years.[3] The move to more interactive multiple unit, double auction markets in recent times prompted this comparative study.

A multiple unit double auction market (MUDA) involves players posting both buy and sell offers and trading in real time. Many MUDA markets are subject to bid reduction rules such as that proposed by Plott and Gray (1990). Bid reduction rules require that offers improve on those standing. The first ask and bid offers stand until better offers are made. In multiple unit markets, an ask with a lower price replaces the standing ask regardless of quantity. Similarly, a bid with a higher price will replace the standing bid regardless of quantity. Offers that do not improve on the standing offer price are rejected. Trade can occur for all or part of an offer quantity. When the full quantity of an offer is accepted, all offers are cleared and the market re-opens. When only part of an offer quantity is traded, the remainder of the offer stands and the opposing offers are cleared.

3. Experimental studies comparing call and double auction structures

There is an extensive body of experimental economics literature exploring the merits of call and double auction mechanisms. Smith (1967) is seen as one the seminal writers in the area. He was the first to articulate and demonstrate in an experimental setting the notion that if markets were formally organised in a double auction setting, a competitive equilibrium would result. Plott and Smith (1978) compared the double market mechanism with other forms of auction mechanisms and found the double auction superior in terms of convergence and allocative efficiency. Smith *et al.* (1982) then followed with a study comparing double, sealed bid-offer, variable quantity sealed bid-offer and tâtonement versions of these auction mechanisms for robustness. They found double auction mechanisms to be superior to the other forms of auction mechanisms in terms of allocative efficiency.

Other studies compared market structures based on price variability. Walker and Williams (1988), for example, compared posted-bid, posted-offer and double auction mechanisms based on offer prices. They found little support for the notion that bid auction prices are higher than double auction prices which in turn are expected to be higher than posted-offer auction prices. McCabe *et al.* (1992), in a study of double Dutch call and double auction variants, found that double Dutch call auctions exhibited significantly lower price variance than their baseline double auction, but did not perform as well based on efficiency. In a later paper, McCabe *et al.* (1993) found that a variant of the uniform price call auction performed nearly as well as

[3] See the Goulburn Murray Water Exchange, http://www.watermove.com.au.

baseline double auctions and the double Dutch auction experiments of their earlier work.

To develop general findings, these works by Smith and others are grounded in decontextualised markets. Moving such findings into policy requires further exploration in contextualised environments. However, contextualised experiments have their limitations. Contextualised environments are often too complex to form theoretical predictions and are criticised for providing little beyond site specific recommendations. To avoid such criticisms, it is important to ensure the correct balance between site-specific parameterisation and characteristics typical of such environments in the experimental settings. Water markets, for example, have a history of being thin as a result of hydrological constraints to trade, dominated by a few players, and are traditionally natural asset markets as a result of changing weather conditions.[4] The case study used in this research is typical of such environments.[5] In this study, multiple unit open call and double auction mechanisms are compared in an experimental setting populated with data from the Goulburn-Broken catchment. While contextualised, the basic characteristics of this catchment are typical of many catchments in the Murray-Darling Basin and throughout Australia generally. The results of the experimentation thus provide general insights into how well alternative markets perform in such environments.

In summary, the history of decontextualised economic experimentation has found the double auction market mechanism superior to other auction in terms of price convergence and allocative efficiency. These experimental studies were based on balanced, decontextualised and single unit markets with defined trader roles (players were told they were a buyer or seller). It is important to ask whether the findings hold in more complex settings. In this paper, while maintaining a level of abstraction to maintain experimental protocols, we ask whether the double auction market is superior in more complex water market environments. This study therefore tested the following hypotheses:

Hypothesis 1: The multiple unit double auction market will be superior to the uniform price open call water market in terms of allocative efficiency.

Hypothesis 2: There will be greater convergence to competitive equilibrium (CE) in multiple unit double auction market compared with the uniform price open call water market.

[4] Such markets are traditionally thin as hydrological conditions often constrain trade to small areas and so few players. Such markets can also consist of heterogeneous farmers who wish to trade in multiple units (not single megalitres) and may choose to be a buyer or a seller depending on market prices and climatic conditions.

[5] A small number of players, growing multiple crops and a few players dominating the market.

4. Parameterisation of the experimental setting

In parameterising an experimental setting the objective is to capture the important characteristics of the issue at hand, while maintaining a level of simplicity in decision making. Doing so allows meaningful predictions, and the results can be replicated, generalised and explored further in field trials. To do this, the decision sets presented to participants in the experiment need to be as simple as possible. Irrigators face a range of complex production decisions, including variable output markets and constraints on the use of other inputs (e.g. labour availability, soil types and asset/machinery specificity). These are of course important, but variations in many of these parameters are unlikely to change the relative merits of different market structures. As a result, only those characteristics directly relevant to the question at hand and are representative of other regions are included in the decision sets presented to the participants. In this light, an economic experiment can be likened to a glasshouse experiment of, for example, a new crop. The conditions in a glasshouse are highly regulated, and only essential likeness to field conditions is included to answer the research question at hand. Following glasshouse experiments, field trials are conducted to further explore the performance of new varieties of crops in the real world. Despite the very controlled conditions of glasshouse trials, the value of the results to the development of agriculture in Australia is well proven. In the same way, experimental economic trials can bring the same level of rigour to policy evaluation. Experimental economic protocols provide the opportunity to test new policy options under controlled conditions without risking their impact on the real world.

In that context, experimental results reported here were parameterised using data from the Goulburn Murray catchment of Northern Victoria. The essence of the research questions deals with differentials in water demands and the marginal value of water. The nuances of specific input and output costs and benefits are left aside for latter field trials. The crop water demands, and maximum targets used in this study were generated using the region's hydrology model REALM. REALM is a nodal network model used by water agencies in Victoria, Australia, to model water movement through their storages and channel networks. The marginal value of water used at each node was calculated from data provided by regional Department of Primary Industry offices. Each player was assigned the characteristics of an extraction node from the model. The following section describes the player characteristics and the associated nodes in detail.

Water trading in the Goulburn Broken catchment is defined in regional zones. A zone is defined as an area in which water can be freely traded without adversely affecting the system's capacity to supply. The information used to populate the experiments was generated from nodal data within the zone 1A/1B region. Farmers located in the 1A/1B zone have historically been the most active in terms of water trading in the exchange. Figure 1 is a schematic of the location of the experimental players within the irrigation network.

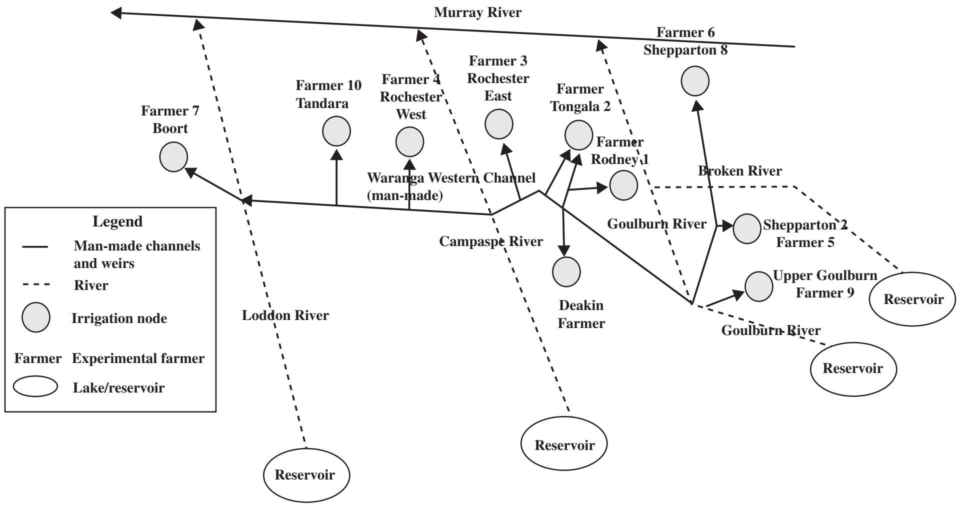

Figure 1 Schematic of the location of the 10 players in the experiment.

Data from the nodal regions were used to populate the player characteristics. The ten nodes used were Rodney, Tongala, Rochester East, Rochester West, Shepparton 2, Shepparton 8, Boort, Deakin, Upper Goulburn and Tandara. For the purpose of the study, data from each node were amalgamated to form a single virtual 'farm' with a water allocation. For the sake of simplicity, six different crop types were used to represent overall crop production in the region. Crop types used were annual pasture, perennial pasture, lucerne, orchard, winter cereal and summer cereal. A summary description of each of the nodes is presented in Table 1.

In essence, each player was given a nominal number of tradable production input units and a declining step marginal revenue function. Their objective was to maximise their income through production and/or trade in input units. Table 2 summarises the water allocations and production options for each of the players. The expected competitive equilibrium for the experiment was estimated from the individual supply and demand schedules as shown in Table 3. The aggregation of the supply and demand schedules for the various players generated the market supply and demand curves, resulting in the competitive equilibrium (CE) illustrated in Figure 2: $(P^{\bigcirc}, Q^{\bigcirc}) = (60, 1286)$.

Market thinness and the associated strategic market power of certain players can be seen by the positioning of the players around CE. There are two players (7 and 10) who have a demand for units at the competitive equilibrium price. There are two sellers – players 1 and 2 – who provide large supplies (471 and 429 units, respectively) at the CE price; player 6 provides a moderate supply (120 units) at the CE price, and five players supply a total of 211 units at the CE price. The competitive equilibrium price and quantity are $p^* = 60$ and $q^* = 1286$. If the price drops as low as $p^* = 42$, two new buyers appear with demands for a total of 14 units (players 3 and 4.) If the price were to fall to 41, there would be three new entrants on the buying side and

Table 1 Node characteristics

Player	Node	Description
1	Rodney irrigation area	The Rodney irrigation area has a total land area of 106,614 hectares. The area lies west of the Goulburn River, and north of the Western Channel. It is fed via the Stuart Murray Canal, which exits west from Goulburn Weir, and Waranga Basin, which lies on the Western Channel
2	Tongala irrigation area	The Tongala irrigation area has an area of 91,314 hectares, and lies west of Rodney, between the Goulburn and Campaspe Rivers. It is fed via the Western Channel, and also from Waranga Basin
3	Rochester East irrigation district	The Rochester East irrigation district is a part of the larger Rochester irrigation area. The area lies west of Tongala, between the Goulburn and Campaspe Rivers, and is supplied with water via the Western Channel. It has an area of 20,193 hectares
4	Rochester West irrigation district	The Rochester West irrigation district is an area of 57,516 hectares. The irrigation district is part of the larger Rochester irrigation area, and lies west of the Campaspe, between the Campaspe and Loddon Rivers. It is fed via the Western Channel
5	Shepparton 2 irrigation district	The Shepparton 2 irrigation district has a total land area of 16,860.5 hectares. This area lies to the south of the Broken River, between the Broken and Goulburn Rivers, and is supplied via a separate channel, which flows out of Goulburn Weir
6	Shepparton irrigation area	The Shepparton irrigation area lies north of the Broken River, between the Broken and Goulburn Rivers, and is fed via a separate channel, which is supplied from Goulburn Weir. The total area of the Shepparton 8 irrigation area is 69,042 hectares
7	Boort irrigation area	The Boort irrigation area has a total land area of 51,325.5 hectares. It is the only node not to be contained within trading area 1A. It lies west of the Loddon River, and is gravity-fed from Loddon Weir
8	Deakin irrigation area	The Deakin irrigation area lies between the Goulburn and Campaspe Rivers. The area is south of the Western Channel, from which it is supplied. The node has an area of 9,259.5 hectares, and is only able to grow four of the six crops available, these being annual and perennial pasture, lucerne, and summer cereal
9	Upper Goulburn irrigation district	The Upper Goulburn irrigation district has an area of 2,358 hectares. This area lies west of the Goulburn River, above Goulburn Weir. It is supplied directly from the Goulburn River, south of Lake Eildon Reservoir
10	Tandara	Tandara is located west of the Rochester West irrigation area, between the Campaspe and Loddon Rivers. It has a total land area of 91,714.5 hectares and is supplied via the Western Channel. Crop six, orchard, is not able to be grown by this region

Table 2 Player characteristics: allocation, usage and marginal values

Player	Water allocation	Crop	MV	Maximum water usage	Player	Water allocation	Crop	MV	Maximum water usage
1	1417	1	169	501	6	844	1	171	334
		2	88	73			2	89	31
		3	82	33			3	84	16
		4	62	267			4	62	285
		5	60	72			5	61	58
		6	41	2838			6	41	1683
2	816	1	164	339	7	309	1	160	286
		2	77	20			2	93	422
		3	68	28			3	81	138
		4	54	46			4	64	73
		5	52	20			5	44	242
		6	35	3531			6	0	0
3	232	1	113	148	8	121	1	181	58
		2	80	59			2	86	9
		3	77	1			3	58	13
		4	58	1			4	40	209
		5	57	35			5	0	0
		6	36	594			6	0	0
4	627	1	113	452	9	76	1	122	11
		2	77	61			2	85	19
		3	73	40			3	78	1
		4	54	76			4	60	4
		5	35	1612			5	58	16
		6	0	0			6	39	73
5	211	1	171	83	10	707	1	116	1262
		2	89	8			2	67	121
		3	84	4			3	57	88
		4	62	71			4	47	103
		5	61	14			5	31	993
		6	41	421			6	0	0

Note: Adjusted MV and water allocation. Original values are too large for use in experimentation.

their demands would be substantial. So the two buyers effectively have only one another to contend with for prices as low as 42. On the other hand, on the selling side supply withholding will be ineffectual both because of the relatively large number of sellers and there are 771 units potentially supplied at prices between 61 and 63. Most importantly, player 5 is a small supplier at the CE price but would become a moderate supplier at $p = 63$, and player 6 is a moderate supplier at the CE price but would become a large supplier at $p = 63$. These facts significantly diminish the market power of the sellers relative to the CE model prediction.

By contrast, there are only five steps in the market demand at values above the CE price $p^* = 60$. There are three steps for player 7 and two steps for player 10. Of these five steps, the last two steps account for 194 of the 1286 units demanded at the CE price. Moreover, buyers have latitude to reduce the price as much as 18 units without new buyers entering the market. So if they collude, the benefit would be the decreased price paid on the first 1092 units,

Table 3 Individual supply and demand

Player	Water allocation	Crop	MV	Units	Supply		Demand	
					Price	Quantity	Price	Quantity
1	1417	1	169	501	89	73		
		2	88	73	83	33		
		3	82	33	63	267		
		4	62	267	61	72		
		5	60	72	42	471		
		6	41	2838			41	2367
2	816	1	164	339	78	20		
		2	77	20	69	28		
		3	68	28	55	46		
		4	54	46	53	20		
		5	52	20	36	363		
		6	35	3531			35	3168
3	232	1	113	148	81	59		
		2	80	59	78	1		
		3	77	1	59	1		
		4	58	1	58	23		
		5	57	35			57	12
		6	36	594			36	594
4	627	1	113	452	78	61		
		2	77	61	74	40		
		3	73	40	55	74		
		4	54	76			54	2
		5	35	1612			35	1612
5	211	1	171	83	90	8		
		2	89	8	85	4		
		3	84	4	63	71		
		4	62	71	62	14		
		5	61	14	42	31		
		6	41	421			41	390
6	844	1	171	334	90	31		
		2	89	31	85	16		
		3	84	16	63	285		
		4	62	285	62	58		
		5	61	58	42	120		
		6	41	1683			41	1563
7	309	1	160	286	94	23		
		2	93	422			93	399
		3	81	138			81	138
		4	64	73			64	73
		5	44	242			44	243
8	121	1	181	58	87	9		
		2	86	9	59	13		
		3	58	13	41	41		
		4	40	209			40	168
9	76	1	122	11	86	19		
		2	85	19	79	1		
		3	78	1	61	4		
		4	60	4	59	16		
		5	58	16	40	25		
		6	39	73			39	48
10	707	1	116	1262			116	555
		2	67	121			67	121
		3	57	88			57	88
		4	47	103			47	103
		5	31	993			31	993

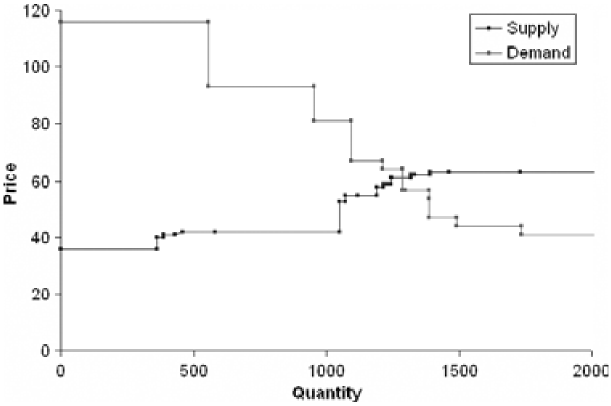

Figure 2 Supply and demand for water.

which is (1286–194) × 18 = 19,656. The cost would be the foregone gains on the purchase of the last 194 units (which would be purchased at the CE price $p^* = 60$). Consequently, buyers have a strong incentive to reduce price.

5. Experimental design and procedures

The experimental design consisted of two treatments and three replicated sessions, with each session consisting of 20 independent repeated rounds as shown in Table 4.

In each session, participants were presented with an allocation of water, up to six different crops with unique marginal values for water and the maximum amount of water they can use in total and on each crop. The participants were told that their objective was to generate income by wisely using and/or trading in water units – their payment depended on their total experimental income. Players had the opportunity to trade their water allocation in either an open call or a double auction environment depending on the treatment.

In the open call sessions, each trading round was open for a period of four minutes (240 seconds). During a call, participants could lodge multiple ask or bid offers. Once a call closed, the central authority ordered the bids and asks offers and cleared the market at the pool-clearing price in the same manner as done by the exchange in Victoria. The bids were filled from the highest bid offer downwards and matched with ask offers from their lowest value upwards until either all the bid quantities were filled or the ask price exceeded the standing bid price. Following the call, all offers were on public display.

Table 4 Experimental design

	Open call	Double auction
Sessions	3	3
Rounds	20	20
Players	10	10

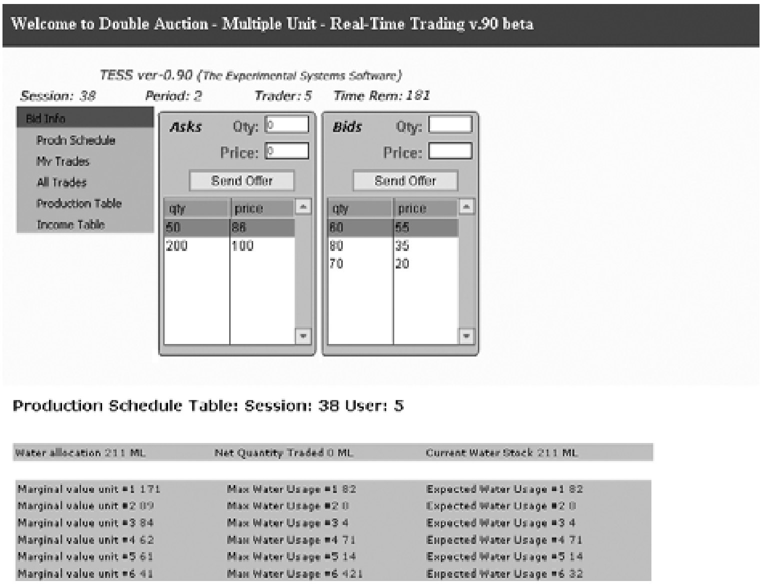

Figure 3 Typical Double Auction Trading Environment.

The double auctions also operated for four minutes (240 seconds). An example of the trading screen is shown in Figure 3. Ask and bid offers were governed by the bid reduction rules by Plott and Gray (1990) in which, as outlined, standing asks and bids have to be improved upon, and market clearance was governed by full and partial trades.

Following the trading period, the available stock of water was automatically allocated to its highest value use. The participants' summary of trades, post-trade water use and associated income were automatically calculated and displayed. Players could view their current stock (stock of water and expected water use), their trades (prices and quantities), all the trades that occurred each round (prices and quantities), water use (by them on each crop round by round) and income (income from crop water use, cost of water bought, income from water sold and round by round player payment).

Two minutes were allotted between trading periods to allow participants to review trade and production information and determine the strategy they wished to adopt in the next trading period. There was no carryover between rounds.[6] It was a groundhog-day experiment. At the end of each experimental session, students were given a cashier's voucher that they could cash at the University cashier's counter.

The participants in the experiments were students studying at Griffith University - an urban university 10 km from the centre of Brisbane, Aus-

[6] It is recognised that carryover is a significant issue for farmers. It was decided that including carryover in this initial set of experiments made the environment too complex at this stage and so beyond the scope of this study.

tralia. As such, it was assumed that the students held no vested interest in the regional context beyond making money in accordance with the induced value theory. While the calibration is detail rich, the players were not made aware of either the name of their irrigation area or the crop types available to them; rather, numbers were used to represent both farm and crop types.

Procedurally, notice boards were located in main thoroughfares of the campus and interested students registered through an online registration system. When sessions became available, they were emailed and registered for specific experimental sessions online. Confirmation emails were sent to a required number of those who register an expression of interest for a session. On arrival, they signed into a university computer within the laboratory. The participants were then instructed to read through a set of PowerPoint instructions available at a designated website and work through a series of comprehension and procedural multiple-choice questions (copies of the instruction files and associated quizzes are available from the author on request). Having successfully completed the quiz, they entered their student number, which gave them a password to enter the experimental software. Once all the participants successfully completed the quiz, the session commenced with two practice rounds prior to the formal session.

The experiments were conducted using the experimental software system (TESS), an experimental software package developed at Griffith University. The software allows bids and asks to be lodged electronically and displays player characteristics in a web real-time environment.

6. Results

In analysing the experimental data, we were looking for differences between the two auction mechanisms in terms of market activity, convergence and allocative efficiency. Mann–Whitney U-tests were used to explore differences between observed market prices and quantities and expected competitive equilibrium. Random effects panel data regression models were used to evaluate differences between the two treatments in terms of number of offers, number of trades, market prices and market quantities.

6.1. Market activity

Table 5 summarises market activity in terms of the number of bids and asks lodged and the number of successful trades conducted. In total, 752 bids and 1333 asks were made in the open calls and 692 bids and 1306 ask offers were made in the double auction across the three sessions. In total, 826 successful trades occurred in the call auction markets compared with 704 in the double auction markets.

Summary statistics of the observed experimental market prices and quantities are presented in Table 6. The average trade price in the call was not sig-

Table 5 Market activity: offers and trades summary statistics

Experiment number	No. of rounds	Duration of trading period (minutes)	Double auction				Open call auction			
			No. of offers			No. of successful trades	No. of offers			No. of successful trades
			Bids	Asks	Total		Bids	Asks	Total	
1	20	4	308	416	724	246	298	411	709	267
2	20	4	170	422	592	228	216	434	650	274
3	20	4	214	468	682	230	238	488	726	285
		Total	692	1306	1998	704	752	1333	2085	826

nificantly different from the competitive equilibrium. However, the average trade price in the double auctions was significantly lower than competitive equilibrium. In terms of quantity traded, the quantities traded in the call market experiments were significantly lower than the competitive equilibrium quantities. In contrast, the market clearing pool prices of the call experiments were not significantly different from the competitive equilibrium price.

Table 7 presents the results of a linear random effects model of trade numbers. There was no significant difference in the number of offers (bids, asks or totals) lodged in the open call compared with the double auction experiments. However, significantly more successful trades occurred in the open call compared with the double market experiments ($P = 0.0287$). This result is not unexpected given that all asks below and all bids above competitive equilibrium will trade. While this should also be the case in the multiple unit, double auction markets the process of working through the bid/ask reduction rule prior to a successful trade occurring may limit the number of successful trades purely on logistical terms.

Table 8 presents the results of a linear random effects model of market prices and quantities. The positive and significant coefficient on treatments suggests that the double auction market prices are significantly lower than those observed in the call markets. Further, the average quantity traded in

Table 6 Market price and quantity summary statistics

Experiment Number	No. of rounds	Duration of trading period (minutes)	Call market		Double market	
			Average price	Quantity traded	Average price	Quantity traded
1	20	4	57.90	1303.2	53.47**	1074.10*
2	20	4	61.00	1191.70**	58.88**	877.45**
3	20	4	62.55**	1138.50**	55.52**	1113.55*
		Total	60.48	1211.13**	55.96**	1021.70**

Notes: Computed competitive equilibrium $p = 60$; $q = 1286$. Mann–Whitney U-test: *Significantly different at $\alpha = 0.05$; **Significantly different at $\alpha = 0.01$.

Table 7 Random effect models of trade numbers

Dependent variable	Coefficient	SE	z	$P > z$	95% Conf. Interval	
Number of trades						
Treatment*	2.052	0.685	3.00	0.003	0.709	3.394
Constant	11.698	0.484	24.15	0.000	10.74	12.64
Wald χ^2	8.98			0.011		
Number of bids						
Treatment*	1.027	1.951	0.53	0.599	−2.797	4.852
Constant	11.524	1.380	8.35	0.000	8.819	14.229
Wald χ^2	0.28			0.870		
Number of asks						
Treatment*	0.593	1.072	0.55	0.580	−1.508	2.695
Constant	21.590	0.758	28.47	0.000	20.103	23.076
Wald χ^2	0.31			0.858		

*Treatment: call = 1, double = 0.

Table 8 Random effect models of market prices and quantities

Dependent variable	Coefficient	SE	z	$P > z$	95% Conf. Interval	
Price						
Treatment*	4.48	1.763	2.54	0.011	1.03	7.94
Constant	55.86	1.247	44.79	0.000	53.41	58.30
Wald χ^2	6.28			0.039		
Quantity						
Treatment*	192.92	71.351	2.70	0.007	53.08	332.77
Constant	1018.07	50.453	20.18	0.000	919.18	1116.98
Wald χ^2	7.31			0.025		

*Treatment: call = 1, double = 0.

the double auction market was significantly lower than that observed in the call markets.

6.2. Convergence

Convergence of the open call pool and average double market prices through rounds is shown in Figure 4. Consistent with the finding that there was no significant difference between the call pool prices and competitive equilibrium, the pool prices converged on CE and progressively reduced in variance. In contrast, while in the double auction experimental data, there are signs of convergence, it is to a level below competitive equilibrium. While neither the double or open call experiments produced traded amounts consistent with competitive equilibrium overall, there were signs of convergence in the quantity traded in the open call experiments, as shown in Figure 5. The quantities traded in the double auction experiments exhibited high levels of variance and poor convergence.

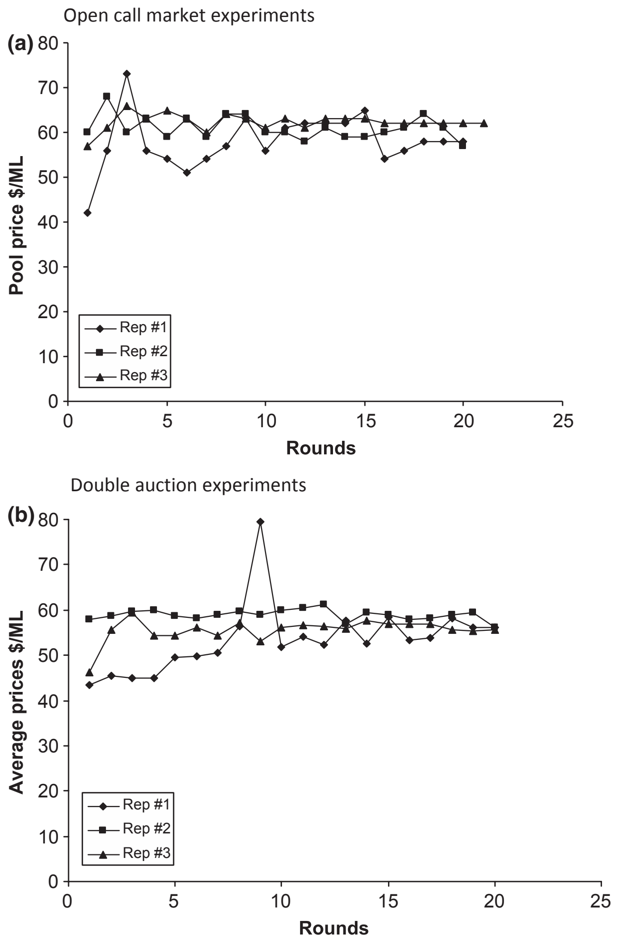

Figure 4 Convergence of market prices through rounds. (a) Open call market experiments. (b) Double auction experiments. Note: There was an anomaly in round 9. This may have been a result of either an error by one or more of the participant's or an intentional mistake to test the market. The market in that session returned to convergence and was not adversely impacted by this anomaly.

6.3. Allocative efficiency

The third measure of comparison used was allocative efficiency. Allocative efficiency is the percentage of possible surplus captured by the market activity in the experimental setting. Figure 6 shows the allocative efficiency levels through rounds. The average allocative efficiency of the open call market experiments was high and showed little variance throughout the rounds. The allocative efficiency of the double market experiments was relatively low and highly variable in the early rounds (first 10 rounds). In the latter rounds, allocative efficiency improved and variance declined. In no round did the allocative efficiency of the double auction experiments equal or exceed that of the

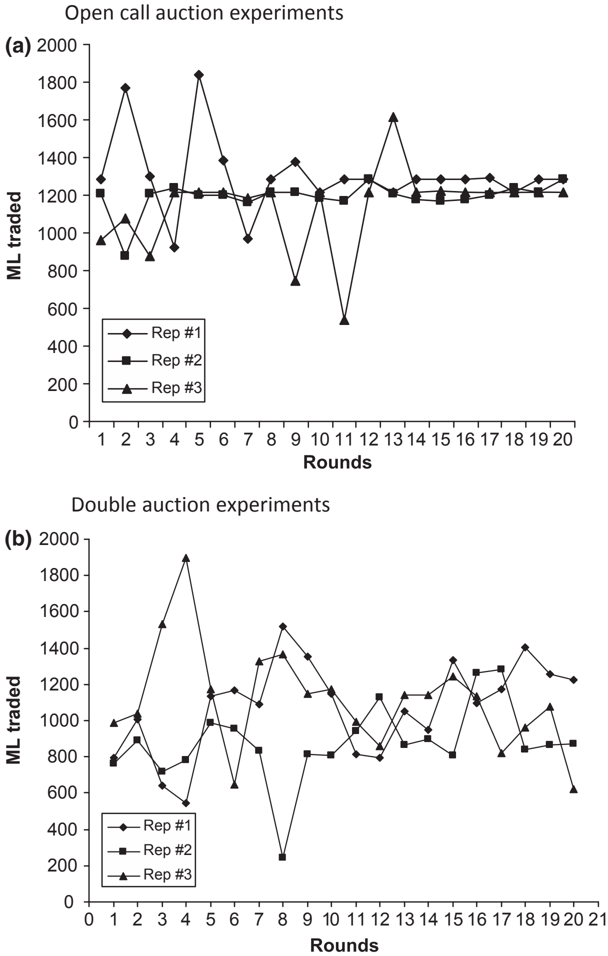

Figure 5 Quantities traded through rounds. (a) Open call auction experiments. (b) Double auction experiments.

open call. Overall, the allocative efficiency of the open call market was found to be significantly greater than the allocative efficiency of the double auction market experiments[7] (Wilcoxon $Z = 5.786$, $P = 0.0000$).

7. Discussion and conclusions

The experimental literature on the relative merits of the double over the call auction market is significant, yet in the study, the double auction mechanism was found to be less efficient than the call market for water. So why then was the call found to be superior? One possible explanation is that in thin markets, there is often the opportunity to manipulate the market price by with-

[7] Call: $\mu = 98.6$, SD $= 0.0157$ Double: $\mu = 91.8$, SD $= 0.0856$.

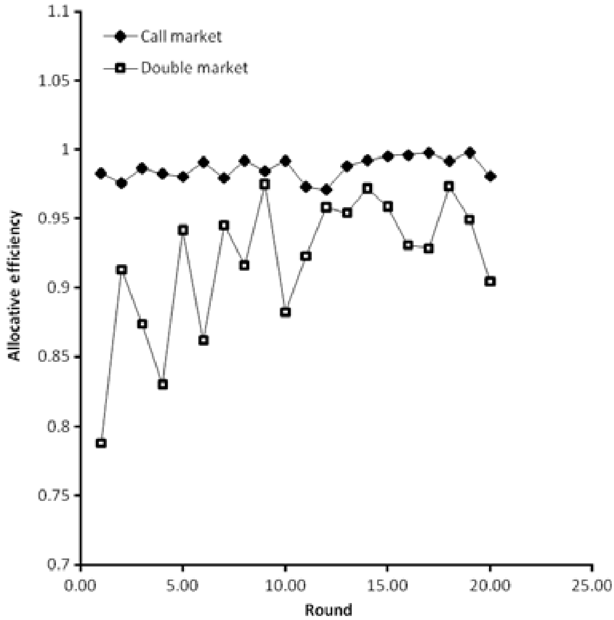

Figure 6 Allocative efficiency of the call and double auction experiments.

holding supply or demand. In previous experimental trials, the markets provided no market power. Markets were not thin. In this study, markets were thin and players have competitive power, which results in double auction prices significantly lower than competitive equilibrium and the quantity traded significantly lower than that observed in the call markets.

The experimental results found in this study could also in part be explained by the experimental design itself. It could be argued that of the two institutional scenarios, the double auction is more complex and requires more sophisticated cognitive processing.[8] It might then come as no surprise that players who were allotted 4 minutes of decision-making time would conduct fewer trades in the double auction format and that they generally were more cautious in this setting. That said the basis of decision making was relatively simplistic compared with the complexity farmers in the field face. Irrigators face a range of complex production decisions, including variable output markets and constraints on the use of other inputs (e.g. labour availability, soil types and asset/machinery specificity). Further research on this topic is warranted to explore how they perform in the field with farmers facing such complex decisions.

In conclusion, this paper explored the notion that the double auction market mechanism is superior to the call market mechanism in thin water markets. While this study is highly contextualised, in doing so, it included key

[8] Simple understanding was tested by requiring participants to complete a multiple-choice test prior to starting a session.

characteristics of many water markets. The market was constituted by few traders in a thin market dominated by buyers, and as such, its findings provide insights beyond the specific case study region to general market mechanism designs for water markets. It was found that the double market mechanism was in fact inferior to the call market in terms of the proportion of successful trades to offers, allocative efficiency and convergence to competitive equilibrium in a series of thin water market experiments.

In choosing water mechanisms for the exchange of water entitlements, further research is warranted. Areas for further research include exploring how strategic interactions in thin water markets impact on market stability, how the different market structures perform in more complex environments, including carryover through rounds, and how sustainable such strategies are through time.

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