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All-in-Auctions for water

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A R T I C L E I N F O

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A B S T R A C T

This paper proposes a novel mechanism for reallocating temporary water flows or permanent water rights. The All-in-Auction (AiA) increases efficiency and social welfare by reallocating water without harming water rights holders. AiAs can be used to allocate variable or diminished flows among traditional or new uses. AiAs are appropriate for use within larger organizations that distribute water among members, e.g., irrigation districts or wholesale water agencies. Members would decide when and how to use AiAs, i.e., when transaction costs are high, environmental constraints are binding, or allocation to outsiders is desired. Experimental sessions show that an AiA reallocates more units with no less efficiency that traditional two-sided auctions.

1. Introduction

Water is perhaps the least-traded commodity input in the world. No newspaper quotes market prices; few investors hold shares in water next to shares in gold and oil; no international water agency tracks the flows, values, supply or demand for water. In most countries, regions and catchments in the world, water is diverted, disbursed and consumed by the same users for the same purposes as it has been for decades. This pattern of quiet use and tradition will not and cannot persist for much longer: increasing water scarcity in many parts of the world—driven by increasing demand and falling supply—means that the economic and social importance of increasing the value of water in use is rising. We need to find ways to reallocate limited water to reflect those values.

Economists prefer market allocations of natural resources over command and control allocations in which a regulator estimates "appropriate" quantities and/or prices (Hayek, 1945). The natural resource subject to more command and control than any other is water, and economists have argued for years that markets for water would increase efficiency and social welfare (Milliman, 1956; Vaux and Howitt, 1984; Rosegrant and Binswanger, 1994; Holden and Thobani, 1996; Zilberman et al., 2007).

Although water can be marketed through bilateral negotiation or markets where the number of buyers, sellers and transactions fluctuates, auctions offer the most efficient way to quickly match buyers and sellers in a given market (McAfee and McMillan, 1987; Milgrom, 1987; Lu and McAfee, 1996). Auctions are particularly relevant with respect to water, since simultaneous reallocation facilitates the planning and delivery of water to users. The fixed costs of establishing an auction mechanism may be too high when a handful of neighbours want to make a few trades, but auctions are worth running when a diverse pool of owners with numerous water rights have widely-varying values for water, when it is important to use a transparent market mechanism to demonstrate highest and best use to outsiders, or when climate-induced or regulator-driven changes in water supply necessitate reallocating more or less water among many claimants (Howe et al., 1990).

Water auctions will deliver poor results when sellers are not present—the problem of participation effects—or sellers' asking prices are too high—the problem of endowment effects. The All-in-Auction (AiA) combines existing ideas from several auction designs to create a novel mechanism that minimizes participation and endowment effects while reallocating water.

The AiA is a uniform price, bid-only auction in which bidders make m bids for n units of water; m is greater than n if water is scarce, and n can vary over time. Bids are ordered during the auction, so that bidders see their successful bids and have the opportunity to enter more bids.[1] The auction has a soft ending—running for a known

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[1] Ties—though unlikely—can be broken via coin flip. Bidders will still be able to add new bids if the resulting distribution is unsatisfactory.

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duration but then ending only after a few minutes without bids—that prevents last-minute reallocations from "sniping" bids that other cannot respond to before a hard ending (Roth and Ockenfels, 2002). After the auction ends, $m > n$ bids are ranked in descending order, the top n bids are accepted, and a clearing price is set equal to the highest-rejected bid: the $n + 1$th bid. All successful bidders pay that price and all water owners receive that price. A participant with three units of rights, for example, may want to buy three units (a neutral participant), four units (net buyer) or two units (net seller).

Participation effects are minimized by making all water available for sale. Such a requirement weakens property rights by removing the right to refuse to consider selling but not to the point of taking property. That is because neutral participants can buy the same number of units in the AiA as they owned before the auction without putting cash on the table, i.e., exercising a no-liquidity option to buy from oneself.[2] Endowment effects are minimized by putting all participants into the position of bidding for water. Such a structure turns the psychology of market participation on its head: participants who ask themselves "How much will I pay for *that* water?" instead of "How much do I want for *my* water?" are more likely to explicitly consider opportunity costs.

The AiA can be used to reallocate either temporary flows or permanent ownership rights. As with any market, rights must be defined and free of legal, engineering, financial and social barriers to trade. An AiA can be used to reallocate water remaining after environmental flow requirements are deducted. An AiA for flows is probably preferable to an AiA for rights: higher variation among subjective values for permanent rights increases the risk and uncertainty in bidding for rights; a series of auctions for flows maximize benefits to permanent rights holders (without preventing them from selling rights in a side market) at the same time as they maximize the value of water in use; and auctions for flows minimize the risk of negative third party impacts or controversy within communities. Although these differences are important in practice, we will use "rights" and "flows" interchangeably in this paper with the knowledge that the AiA can be used for either.

It would be a mistake to plan and implement an AiA across many political and hydrological boundaries due to problems with delivery, third party impacts, water quality, and so on; see Clayton (2009) on these issues in the western US. It is better to start with separate AiAs within different irrigation districts or wholesale water agencies, for example, where users with quantified individual rights to water can vote to implement an AiA among themselves. Water users in one area, district or agency with active AiAs can then allow outside participation or connect with other AiAs.

From a social perspective, the AiA will improve welfare when participation and endowment effects are large relative to transaction costs. The impact of participation and endowment effects—and thus the benefit from reducing them—will be greater when there is more water to trade among more users with larger variations for values of water-in-use; a small number of homogeneous users with little water could probably reallocate their water more efficiently while drinking a cup of coffee than through the AiA mechanism. From an individual perspective, the AiA will improve welfare for water-poor net buyers who gain when greater liqidity/lower prices result from the participation of net sellers or neutral participants. Net sellers will gain to the extent that they choose cash over water. Neutral participants lose to the extent that they spend a few minutes buying back their water within the AiA, but they also gain knowledge about the value of water to their neighbours and themselves.

The paper is organized as follows: The next section describes markets and auctions for water. Section 3 describes the AiA in detail. Section 4 describes a lab experiment that compared the AiA mechanism with two-sided auctions and tested for participation and endowment effects. Section 5 suggests how to implement the AiA in the field. Section 6 concludes.

2. Markets and actions for water

Water is used around the world, but trade in water—where physically possible—is often thwarted by institutional, cultural, legal and social barriers; see Calatrava and Garrido (2006); Garrido (2007a,b). The occasional trades that do occur tend to be simple exchanges ("I'll give you some water now for the same amount in the future") or one-way transfers from rural to urban users. Liquid informal and formal markets are relatively rare; informal markets tend to dominate where water rights are vague, e.g., in India and Pakistan; formal markets function where water rights are clear and conveyance infrastructure facilitates trading, e.g., in Chile, Australia and the US states of Arizona, California and Colorado; see Wahl (1993); Haddad (1996); Easter et al. (1999); Hanak (2002); Howitt and Hansen (2005); Scarborough and Lund (2007); Adler (2008).

Australia's water market is widely-cited as the largest in the world by volume, value and percentage of total water rights traded—even considering complications from laws that vary by state, inter-district transfer penalties, infrastructure constraints, and changing environmental demands. Taylor (2008) reported $A1 billion in water trades during their record drought, in volumes that amounted to 30 percent of total water flows. AiAs can complement Australian markets by facilitating reallocation within irrigation districts.[3]

Auctions are probably rarer than markets for water because water rights and flows are not easy to group and sell in homogeneous auction lots. Cummings et al. (2004) tested an experimental reverse (procurement) auction in which Georgia farmers competed to offer their rights to withdraw irrigation water to the state government as buyer; they also reported the performance of a modified form of their mechanism that the government subsequently ran. Hartwell and Aylward (2007) describe a reverse auction in which farmers compete to sell water to a buyer targeting greater in-stream flows. Finley (2012) describes a recent auction in which energy companies outbid farmers for the rights to new water flows. There are failures for each of these auction successes. Boxall (2009), for example, reported on an auction for groundwater surpluses in Southern California that ended up failing—not due to a lack of interest but a failure to guarantee that buyers could use a local monopolist's network to take delivery (GWI, 2009).

The novelty of water auctions does not mean that farmers—the most likely auction participants—are immune to their charms. Farmers have used auctions for livestock and crops for decades, even centuries. In recent years, they have participated in auctions for more exotic goods and services. Cason et al. (2003) report the results of an auction to reduce non-point source pollution; Kirwan et al. (2005) describe a reverse auction in which farmers bid to participate in a land conservation program. These academic treatments do not capture the full range of auction activities, of course, since academics do not spend too much time investigating activities that have moved into regular use. The USDA's website, e.g., has 38 documents discussing reverse auctions.

[2] The small transaction cost to exercising this option may be worth inflicting if the accompanying increase in social surplus is large.

[3] Tisdell and Ward (2001) ran an experimental auction among Australian farmers.

3. The All-in-Auction

The AiA auction is designed to maximize liquidity and efficiency in water reallocation using two features:

(1) All rights are for sale—minimizing participation effects.
(2) These rights go to high bidders—minimizing endowment effects.

This mechanism uses soft paternalism (your rights are for sale, but you can buy back those rights) to reframe the price of rights from free to the AiA price by making opportunity costs explicit. Owners who may have used water for years without thinking now start with nothing; they only get water if they bid more than others.

The AiA should deliver greater efficiency than status quo allocations or other market designs because it increases liquidity and decreases endowment effects, but its design delivers a third advantage—a relatively painless way to reallocate water to uses with higher social values. The AiA reallocates with lower costs than traditional methods that often involve political controversy, legal disputes and/or generous compensation because it allows existing rights holders to buy back as many units as they own without fear of being outbid by others at the same time as it makes it easy for other holders to sell their water for cash.

In the next subsections, we show how the AiA works using a simple example, discuss how the AiA fits within existing auction theory, and explain how the AiA addresses property rights, participation effects, and endowment effects.

3.1. An example

Mr. A, Mr. B and Mr. C all use water in an irrigation district where farmers' rights to water are based on the seniority of their claims. In this "first in time, first in right" prior appropriation system, senior rights get water before junior rights. In this dry year, the junior rights held by Mr. C and other farmers (we ignore them for this example) are not "wet" so the irrigation district decides—using the normal decision-making process—to reallocate limited supplies using an AiA. This auction for temporary water flows does not change ownership of underlying water rights; they remain with their owners.

Table 1 shows how many units farmers own before the AiA and their bids in the AiA. Table 2 shows these 13 bids for nine units, ordered from highest to lowest. The nine top bids are successful, but the price everyone pays—and owners receive—is $26, a price determined by the highest-rejected bid, the tenth bid.

Table 3 reconciles units and funds. Mr. A buys two units, Mr. B buys four units and Mr. C buys three units. Mr. A is a net seller, Mr. B is a neutral participant (bidding high to ensure that he buys as many units as he owns), and Mr. C is a net buyer. Mr C pays $78 for his three units; Mr. A receives $78 for the three units he sold. The results show that Mr. A prefers some money to all his water, Mr. C prefers some water to his money, and Mr. B prefers to keep all his water. Note that Mr. B's high bids reflect inframarginal demand; the final price is only influenced by bids close to the margin (Hahn, 1988).

Table 1
Bidders submit as many bids as they want for the *n* available units.

	A	B	C
Starting units	5	4	0
Bid per unit	55	200	60
	34	200	45
	26	200	30
	12	200	22
	2		

Table 2
Bids for *n* units are ranked in descending order, the top *n* bids receive units, and winners pay the $n + 1$th price—$26/unit here.

Bidder	Bid
B	200
B	200
B	200
B	200
C	60
A	55
C	45
A	34
C	30
A	26
C	22
A	12
A	2

How efficient is this result? An assumption that bids are equal to willingness-to-pay allows us to calculate values for the pre-auction distribution of units equal to 129 for Mr. A, 800 for Mr. B and 0 for Mr. C—or 929 in total. Compare that number to the post-auction total value of 1024; the AiA-induced redistribution of water has increased social value by 95. This result is obvious, of course, since the AiA allocates water from high points on individual demand curves to the highest values on an aggregated demand curve.

Auction theory is discussed in the next section, but it is useful to explain the use of a single price instead of pay-as-you-bid, discriminatory pricing here. Different prices would mean that neutral participants could make or lose money—rendering the AiA politically infeasible—and make it impossible to discuss a single price at which the auction cleared, a price that would be useful for operating or planning purposes. A single price can lead one to worry about strategic bidding: a net seller may try to increase his overall revenue by bidding for a few units on the margin, but that strategy can backfire. Mr. A, for example, could raise his bid from $26 to $29 to make an additional $9, but he only knows the highest *rejected* bid. A bid of $31 would result in him purchasing an additional unit and losing $28 in cash. Mr. A would have a harder time manipulating the clearing price in a real AiA in which dozens of bidders place hundreds of bids. Uniform prices are easy to understand, result in a single price, and leave neutral participants financially intact.

3.2. Auction theory

Although the AiA may not be the first design where sellers are all-in or sellers can affect the price they receive by bidding as buyers, its real innovation is an application of several existing ideas to the problem of water misallocation.[4] This adoption occurs within a framework that conforms to the institutional context under which water rights and flows are managed. The result balances reallocation to those with a higher willingness to pay with the need to protect owners of water rights from involuntary takings.

The AiA draws on existing theories of multi-unit auctions where interdependent bids can render single-unit auction rules (e.g., English, Dutch, Vickrey, etc.) inefficient. Bidders in a multi-unit uniform price auction, for example, have an incentive to bid high on their first unit and shade down their bids on subsequent units because, theoretically, one's subsequent bid may determine the price paid for all units (Kagel and Levin, 2008). Ausubel (2004)

[4] Auctions for financial transmission rights (FTRs) in the electricity industry reduce mismatches between supply and demand for capacity according to bids from users and speculators, but FTR revenues are often apportioned to the utilities providing physical transmission (Joskow and Tirole, 2000).

Table 3
The n units are allocated to high bidders, with Mr. C (a net buyer) transferring money to Mr. A (a net seller) at $26 per unit. Mr. B, a neutral participant, leaves with as many units as he owned before the AiA. His cash balance does not change since he pays $26 for each of the four units he buys but receives $26 for each of the four units he brought to the auction.

	A	B	C
Starting units	5	4	0
Units bought	2	4	3
Cash received	130	104	0
Cash paid	52	104	78
Change in cash	78	0	−78

solved this problem with a discriminatory price design where bidders clinch units in ascending order at prices just below their bids, achieving efficiency for multiple units in the same way that Vickrey (1961) did for single units. Although this process transfers units from those who value them least to those who value them most, it (as noted above) results in multiple prices that would change cash balances of neutral sellers, an outcome that would weaken a key element in the AiA's design.

Two-sided multiple-unit auctions with multiple sellers are more efficient when sellers and buyers submit their respective supply and demand schedules, but multiple equilibria make it difficult to calculate optimal bidding strategies or efficiency for any format besides the generalized Vickrey (Ausubel, 2004). Researchers who have used experiments and simulations to explore optimal bidding behaviour (e.g., Alsemgeest et al. (1998); Kagel and Levin (2001); Hailu and Thoyer (2006)) found that two-sided auctions lose efficiency when too few sellers participate (a participation effect) or sellers ask high prices (an endowment effect). These effects can result in suboptimal allocations, which the AiA circumvents by pooling all units for sale and turning sellers into buyers. Parente et al. (2008) explore this option by making sellers into buyers, but they do not examine participation effects or endowment effects for items owned outside the lab.

Hahn (1988) proposed a design similar to the AiA, a "zero-revenue auction" that gives equal endowments to bidders with different induced-demand schedules, auctions units based on the highest-rejected price, and distributes revenue equally (in proportion to endowments). Hahn wanted to use this mechanism to efficiently reallocate assets among citizens without generating revenue for the government. The AiA differs by forcing participation on subjects with unequal endowments of goods they may have held and used for years.

3.3. Property rights and participation effects

Economists do not usually consider the impact of participation effects—rather, non-participation—on market efficiency since sellers who bypass trading opportunities hurt only themselves, but it is important to improve participation in markets for goods for which efficiency also produces positive externalities. In response to the 1990 Clean Air Act, the US Environmental Protection Agency (EPA) jump-started the market for sulphur dioxide permits by taking 3 percent of all permits from their owners and selling them in an auction that facilitated growth of a bilateral market that eventually grew much larger (Joskow et al., 1998). Farmer participation in the market for environmental services, likewise, had big impacts on social welfare (Wünscher et al., 2008). Water market reallocations that improve efficiency can also create positive spillovers by, for example, reducing water use for a given output, facilitating reallocation water movement towards environmental flows, improving cost-efficiency by putting an objective price on conservation, and so on.

The benefits of functioning water markets are not just theoretical. It is widely acknowledged that a *lack* of trading in Chile's water rights market has reduced efficiency and increased social tension: some towns have lost access to water where industrial and mining concerns hold rights for potential future use. The opposite has happened in Australia, where participation has increased familiarity with the legal, logistical, and psychological dimensions of water markets. The resulting increases in traded volumes—taking weather and allocations into account—have improved both short-term and long-term liquidity (NWC, 2011).

The AiA mechanism is quite aggressive in maximizing participation to increase efficiency over what we would see with a voluntary market or auction. Consider, for example, a market in which a few buyers and sellers show up. They will represent some portions of aggregate supply and demand curves that will be missing sections belonging to those absent from the market. The result will be lower liquidity (fewer available units) and weaker movement towards the clearing price (less bidding). The AiA "fills in" those missing portions by putting all units up for sale (turning the supply curve from an aggregate of individual willingnesses to accept into a single quantity to be sold) and allocating those units according to demand-side bids. The efficiency gains of the AiA rise with asymmetries in values between those who hold rights (that may not have been marketed for decades, if ever) and those who would use them.

Property rights advocates will not approve of the AiA's presumption that all units are for sale, but their objection may be reduced if, first, it is easy to recover rights in the AiA and second, if the costs of participation are small relative to the benefits from the AiA, i.e., greater liquidity, lower transaction costs, greater surpluses, and clarification of water's value to owners, users and bystanders.

We know from the example above that Mr. B had no trouble keeping his units by bidding high, but this action required that he attend the AiA and thereby incur non-trivial transaction costs. We can lower even those costs by taking advantage of the AiA's characteristic of selling pooled units to high bidders without sellers needing to take any action—unlike the case in a spot market or two-sided auction. From this description, we can see that passive sellers need not even be present sellers. The tricky part, then, is finding a way to make it easy for passive sellers to sell while making it easy for neutral participants to buy from themselves.

We do this by allowing any water owner to pre-bid to buy back $b_i \in [1, n_i]$ of their n_i unit endowment at least some time before the AiA starts. Pre-bidders need not attend the AiA to buy back those b_i units because their bids will be entered at a higher-than-clearing-price level to ensure that they win those units. They will be paid the clearing price for each of the $s_i = n_i - b_i$ units they sell. Pre-bidders who attend the AiA will have their pre-bids cancelled; they can then bid to win $w_i \in [0 \ldots n_i \ldots m_i]$ units, with $m_i \le n$, the total number of units available.

Thus, we can see the strategy for those who want to protect some or all of their endowment n_i is to prebid for b_i and not show up. The strategy for those who want to sell all is do nothing. The strategy for those who want to buy more than n_i is to show up, bid high for n_i units and then bid for as many additional units as they want. The risk-averse but curious can pre-commit to buy b_i units but cancel that sale should they end up deciding to go to the AiA—and make it there without an unexpected flat tire.

Besides these costs and benefits to putative participants in the AiA, we also need to recognize the strategic and political barriers to maximizing participation in an AiA. Water rights owners may be averse to using an AiA if the resulting changes in water flows allow policy makers to conclude that "surplus" water can be redirected to social uses, or if the AiA clarifies implicit wealth they would prefer

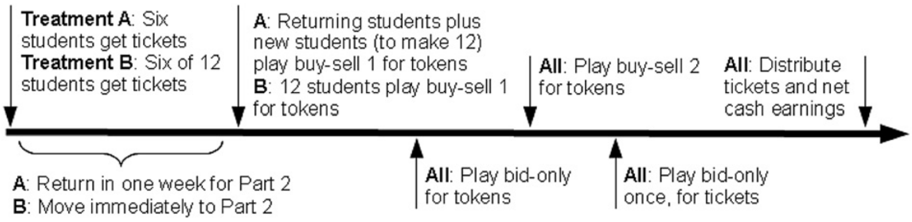

Fig. 1. Treatments A and B had identical timing except that the delay between Parts 1 and 2 was one week in Treatment A and a few minutes in Treatment B.

to keep private (Hahn, 1988).[5] The final barrier rests with politicians and bureaucrats who might object to an AiA (or any mechanism) that reduces their discretionary power by allowing water users to direct water flows (Zetland, 2009).

3.4. Endowment effects

Prospect theory explains why people may put a higher willingness to accept (WTA) on an endowed good than they would be willing to pay (WTP) for that same good (Kahneman and Tversky, 1979; Kahneman et al., 1990). The existence of endowment effects in laboratory settings has led many to conclude that these effects exist outside the lab and recommend policies that attenuate them. Others challenge these lab conclusions, claiming that endowment effects are the residual of carelessly designed experiments. Engelmann and Hollard (2009), for example, eliminate the endowment effect by forcing participants to trade their endowments. Plott and Zeiler (2007) find "endowment effect theory" to be less than robust. They show that the gift context ("I am giving this coffee cup to you" at the start of an experiment), asymmetric knowledge of values ("this cup must be valuable to them because they want it from me or because they emphasized its value"), and public commitments to trade ("put your hand up if you want to trade") create attachments that can explain the gap between WTP and WTA. Attachment theory, therefore, holds that circumstances add value to a good that is just the same as other, non-possessed goods.

That said, Plott and Zeiler exclude "the potential role of ownership in the creation of features of goods that hold special values, such as sentimental value, emotional attachment, familiarity, etc." [p. 1453]—effects that may apply to water. First, water rights have often been used for decades on land settled by ancestors of the current generation. Second, water rights are often given to settlers and farmers by legislative or bureaucratic acts; they are therefore valued as a gift, not just a commodity. (The gift effect may not exist if rights are earned by settling vacant land for five or ten years, but the sentimental value resulting from that process is likely to be stronger.) Third, water is essential for community existence and often distributed by organizations with deep cultural and social roots. Fourth, water trades take place in public, where peers and other members of the community can witness and pass judgement on the adequacy of the decision to sell and the price achieved. These observers will affect WTA for all but the hardest-nosed traders. Fifth, AiA are not really about overcoming endowment effects as much as putting all rights into play and allocating them to bidders who treat them as seasonal inputs instead of permanent assets associated with an income stream. Finally, water rights are often associated with—or even tied to—land ownership. These rights affect land value (Veeman et al., 1997), and they certainly gain value from the perception that they make the land useful.

4. Testing the AiA in the lab

Fig. 1 illustrates session timing for two treatments designed to test the AiA; see the Appendix for detailed instructions.

In Part 1 of both treatments, each of six players received a pair of movie tickets that would be auctioned later in the experimental session. Players knew that tickets would have cost them either $16 (67/72 players were students) or $20 (remaining players) had they bought them.[6]

In Part 2, tickets were collected and held by the experimenter, endowed players were joined by six others, and all 12 players completed three computer-based experimental auctions before bidding for the movie tickets in a fourth and final auction. The six non-endowed players used money earned in the first three auctions to bid for movie tickets. Endowed players were allowed to bid for their tickets without a price limit and additional tickets subject to their cash earnings. The final AiA for tickets was identical to an AiA for water except for the shorter period of endowment, the small number of units (pairs of tickets), players (12 people), and hard ending (between 120 and 150 s)—pragmatic constraints that did not alter the basic AiA design.

Treatment A tested for a weak participation effect by placing one week between Parts 1 and 2; Treatment B had no delay between parts.[7] Although this lab test for a participation effect is clearly different than the participation effects among water rights holders who may have received rights years or decades before the opportunity to participate in markets arises, we tried to reproduce it by distributing tickets in advance of the auction and then watching who returned for Part 2. A failure to return one week later—like a failure to turn up at an auction after holding rights for years—indicates that we cannot assume that all those who promise to come (or should come) will do so, thereby reducing efficiency to the extent that market demand and supply curves are missing pieces. The solution to the participation effect is to establish a pre-bid process as described above, but our lab experiment merely tested for the presence of such a no-show effect while putting in place a mechanism to replace no shows with new participants. We tested the endowment effect by comparing bids among players endowed for different durations in Treatments A and B. We also tested each of the four auctions for efficiency by dividing actual player earnings by the maximum they could earn, a value that depended on the demand schedules we gave to players. An efficient allocation of water would be measured in the same

[5] Imperial Irrigation District (IID) was forced to sell water to the Metropolitan Water District of Southern California when it was charged with wasting water (Graff, 1985; Haddad, 1999). That event did not improve market performance in IID. A more recent reverse (procurement) auction run at IID failed when too few farmers were willing to participate (Lusk, 2008).

[6] Sayman and Onculer (2005), in a meta-study of WTP–WTA literature, report that players limit their bids when they have price data. Indeed, final prices for ticket pairs in AiA sessions were $3, $5, $5, $12, $14, and $16.

[7] Rosenboim and Shavit (2009) found that players who hold experimental cash for two weeks make lower bids than players given cash two hours before an experiment, i.e., endowment effects lead them to conserve "their" cash.

way, should one be able to quantify water user demand functions, but that is not possible. All we know is what holds in any market: non-trembling reallocations increase efficiency.

4.1. Description of auctions

All experimental sessions for both treatments followed the same pattern: a buy-sell (two-sided) auction, a bid-only (AiA) auction, another buy-sell auction, and a final bid-only (AiA) auction for movie tickets. Non-ticket auctions for units were repeated eight times, each with a new set of endowed players.

Buy-sell 1: Six of twelve players were "actively endowed" with units, which they could sell in two-sided auctions in which buyers could accept seller asks at the same time as sellers could accept buyer bids.
Bid-only: Six of twelve players were "passively endowed" with units. They could *not* decide how many units to sell in a bid-only auction in which the highest n bids pay a price equal to the $n + 1$th bid for all units, but they received revenue from any units they did not buy back from their endowments via their own bids. This structure allowed players to buy back their units at no net cost or be net buyers or net sellers.
Buy-sell 2: A repeat of buy-sell 1 that tested for learning effects.
Bid-only ticket: This auction had the same in structure as bid-only, but it was used to allocate the pairs of movie tickets that some players received as endowments one week earlier (Treatment A) or at the beginning of the session (Treatment B).

4.2. Hypotheses

H_0^1: In Treatment A, there is no participation effect, i.e., all players from Part 1 will come one week later to participate in Part 2.
H_0^2: Players will not exhibit any endowment effects, i.e., the distribution of units at the end of auctions will be the same for endowed and non-endowed players in auctions for:
(1) Tickets.
(2) Units in Buy-sell.
(3) Units in Bid-only.
H_0^3: Ticket endowment effects in Treatments A and B are identical, i.e., endowment effects do not strengthen over time.
H_0^4: Non-ticket endowment effects in Buy-sell 1 & 2 and Bid-only auctions are identical.
H_0^5: Efficiency does not improve between Buy-sell 1 and 2, i.e., no learning effect.
H_0^6: Efficiency is the same for Buy-sell 1 & 2 and Bid-only, i.e., no structural effect.

4.3. Experimental sessions

Each treatment was tested in three sessions with 12 players each. Two players were added to replace two players who did not return to Part 2 of Treatment A (a weak participation effect), bringing the total number of players to 74.

Player confusion in beta sessions led to a longer tutorial on demand schedules and bidding, additional time to play with the software, and more questions and answers during practice rounds, but some players found the software complex, demand schedules confusing, and the time element challenging.

4.4. Experimental results

We could not always test for statistical significance due to small player pools. All results refer to periods 5–8 for non-ticket auctions. Starting efficiency given endowments randomly distributed to four of 12 players with different induced demand schedules ranged from 1920 to 2060 experimental units (42–45 percent of the maximum efficiency of 4624 units). It was easy to make Pareto-improving gains from trade between endowed and non-endowed players because demand curves gave no value to one or more endowment units above a given maximum. Final efficiency in both treatments ranged from a minimum of 3035 (66 percent efficiency) to a maximum of 4559 (99 percent) with a median value of 4171 (90 percent).

H_0^1: *In Treatment A, there is no participation effect, i.e., all players from Part 1 will come one week later to participate in Part 2*. Two of 18 players did not return for Part 2, falsifying the idea that all participants attend all markets (more on this trivial finding below).
H_0^2: *Players will not exhibit any endowment effects, i.e., the share of final allocations will be the same for endowed and non-endowed players*.
(1) *Tickets.* Two players did not return to Part 2. Of the remaining 16 who held tickets for one week, eight bought their tickets back and eight failed to buy them back. Thus, ten of 18 (56 percent) kept tickets in Treatment A. In Treatment B, only eight of 20 players (40 percent) who held tickets for the session bought them in the auction. These results are consistent with an endowment effect for tickets.
(2) *Units in Buy-Sell.* Reject. Endowed players still owned 6.0 and 5.1 of their 12 unit endowments at the end of Buy-sell 1 and 2, respectively. Unendowed players owned 3.0 and 3.1 units, respectively. All these final holdings are statistically different from 4.0 (the efficient number of units to hold, given demand schedules) at the 99 percent level (unpaired t-tests).
(3) *Units in Bid-only.* Fail to reject. Endowed and unendowed players bought 4.3 and 3.8 units, a number that is not statistically significant from the efficient quantity of 4.0 units at the 95 percent level (unpaired t-tests).
H_0^3: *Ticket endowment effects in Treatments A and B are identical, i.e., endowment effects do not strengthen over time.* Two of the 18 players endowed for one week in Treatment A never returned, eight bought their tickets, and eight (44 percent) did not buy tickets. Eight of the 20 players endowed for the duration of a session (18 in Treatment B plus two who replaced players who did not return after a week in Treatment A) bought their tickets (buy from self), and 12 (60 percent) did not buy their tickets. This result is consistent with an endowment effect, i.e., players who held their tickets longer were more likely to bid for them in the final auction.
H_0^4: *Non-ticket endowment effects in Buy-sell 1 & 2 and Bid-only auctions are identical.* Reject. As with H_0^2, endowment effects were stronger in Buy-sell (where players must act to sell units) than in Bid-only, where they need to buy their units if the want to keep them. These effects are significant at the 1 percent level when comparing bid-only with buy-sell 1 or 2.
H_0^5: *Efficiency does not improve between Buy-sell 1 and 2, i.e., no learning effect.* Fail to reject. In Treatment A sessions, efficiency was 89 percent and 88 percent in buy-sell 1 and 2, respectively (p-value 0.73). In Treatment B sessions, efficiency was 89 and 91 percent, respectively (p-value 0.23).
H_0^6: *Efficiency is the same for Buy-sell 1 & 2 and Bid-only, i.e., no structural effect.* In Treatment A and B sessions, average buy-sell efficiency was 89 and 90 percent, respectively. Bid-only efficiency was 93 and 89 percent in Treatments A and B. Buy-sell and bid-only were statistically identical for Treatment B, but not for Treatment A (p-value ≤ 0.05).

4.5. Discussion

The existence of participation effects, or the lack of total participation in markets, is obviously true for most markets in the world and obviously trivial in most of those markets, but their existence is troublesome when allocation of an undertraded asset such as water results in social as well as private impacts. The AiA explicitly addresses this problem by putting all units for sale and requiring pre-bids for participants who wish to buy back their units.

These sessions also clarified the importance of transaction costs and endowment effects among those who held tickets for a week. Although two-sided auctions are efficient, they may suffer from under-selling if either endowment effects or transaction costs reduce seller participation. Each of these effects is likely to be strong in auctions for water, where, respectively, endowment effects accrue over years and water rights owners are skeptical of or unfamiliar with markets for one of their critical inputs.

The efficiency differences (or lack thereof) between bid-only and buy-sell auctions are also not groundbreaking, but they indicate that the AiA's bid-only structure works fairly well, probably because its design delivers 100 percent efficiency to players who bid their demand schedules. Players in buy-sell auctions would have a harder time hitting that efficiency because they need to manually match bids and asks. This paper is not designed to resolve any arguments over the relative efficiency of these auction structures, merely to show that the AiA's structure—a structure that requires that units be pooled for sale—can deliver efficiencies similar to those we see in more familiar two-sided auctions.

5. Adapting AiA to the field

AiAs can be adopted by any organization seeking to reallocate water by defining the quantity of available water, distributing rights to that water to owners (according to their seniority, customary shares, and so on), and using the AiA to allocate water to high bidders and cash to net sellers. Organizations with complex or constrained infrastructure, requirements that flows go to the environment, trunk canals, etc. can run a handicapped AiA that reflects constraints; see Murphy et al. (2000); Raffensperger and Milke (2005); Plagmann and Raffensperger (2007); Raffensperger et al. (2009).

The following instructions can be used to explain the AiA in the field:

(1) Establish demand for water by asking participants to write down the number of units of water that they want to buy, with a value for each unit. (Policy makers who need to know how the AiA works can be given a card with six squares, each showing the value of a unit of water.) These values, which may be the same or different, will be low when other water is available or the crop is not worth much and high when water is needed to keep an orchard or vineyard alive. The total number of units that players want to buy (m) does not need to be known by anyone.
(2) Establish the supply of water by asking participants how many units of wet water they have—a quantification that may differ from their long-term rights. (Policy makers can be given 1–6 units, based on rolling a six-sided die.) The total supply (n) is known by everyone. Water scarcity implies $m > n$, i.e., demand exceeds supply. Large values for m and n may need to be reduced if there is not much time for a demonstration, but they can be sorted by computer in the case of implementation.
(3) This supply of n units of water is put into an AiA in which bids are recorded, and the highest n bids are listed and updated until there are no new bids. The auction then ends, the highest n bids are accepted, and water units are distributed. The price of water is set to the $n + 1$th bid.
(4) Individual profits are recorded as the total value for units of water purchased in the auction, less the cost of those units, plus any cash earned from sales.
(5) Players then compare and discuss their strategies, actions and profits before repeating the game as needed. It is also helpful to compare values under ex-ante endowments to values after AiA reallocations.

6. Conclusion

All-in-Auctions (AiAs) maximize the reallocation of water or water rights among water users to direct water to its highest economic and social uses. AiAs force water rights holders to put their water up for sale, a weakening of property rights that does not have a material impact on owners due to their ability to buy back their own rights without concern for price or liquidity—meaning, in other words, that the AiA nests the status quo (no trade) within its potential set of outcomes, less trivial transaction costs. The benefits from reallocation and value discovery in the AiA more than offset the small costs of operating the AiA or inconvenience to participants who merely want to buy back their water.

AiAs have greater transaction costs than small-scale trading, but they are more efficient in areas with many farmers, large amounts of water, diverse crops and soils, divergent values for water, and/or dramatic changes in supply or demand. AiAs can be configured to allow for environmental constraints, distribution bottlenecks, and/or participation by outsiders. AiAs take us a long way towards the goal of developing water markets that are efficient yet functional within current institutional constraints, a function whose value rises with water scarcity.

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Appendix. Auction instructions

These auction experiments were run at UC Berkeley's X-Lab in December 2009 under approved protocol CPHS #2009-4-10. Players earned an average of $30–33 in cash and tickets. In Treatment A sessions, Part 1 took about 10 min. Part 2 of Treatment A sessions and Parts 1 and 2 of Treatment B sessions took less than 100 min. Players thus made over $15/h.

Part 1 instructions

In Treatment A, six players completed a questionnaire and received two tickets each. They were told to come back one week later if they "wanted the opportunity to sell their tickets" in Part 2. They were then joined by additional unendowed players to make a group of 12. In Treatment B, six players—chosen randomly from 12 players—received tickets before the entire group moved to Part

2. In both treatments, tickets were collected from owners at the start of Part 2 and redistributed to buyers who won them in the second bid-only auction at the end of Part 2.

Part 2 instructions

(1) Your goal is to maximize profits. You get profits from owning units and tokens.
(2) Everyone starts with a loan of tokens. This loan will be deducted from your earnings (from units owned and trading) at the end of each auction. If a positive balance remains, it will be added to your earnings for the day. If a negative balance remains after the loan is repaid, then your earnings for the day will be reduced. Your earnings for the day will *never* be lower than $5 [per IRB standards].
(3) Everyone has been randomly assigned a demand schedule for this game. The demand schedule tells you the value of each unit *to you.* Others may have different values for units. Your demand schedule may change in each auction. In all cases, the value of your second unit is less than your first unit, your third unit is less than your second unit, and so on…“Last unit” refers to the value of a single unit, *given* the number of units you already have.
(4) If you pay less for a unit than its value to you, you make a profit. If you pay more than its value, you make a loss.
(5) In **buy-sell** auctions, some of you will begin with units and some will not. All players can buy units. You can only sell units that you have. You can only buy units when you have tokens (no negative balances). The players who begin with units *may* change each time we repeat this auction.
(6). In **bid-only** auctions, nobody begins with units. You can buy units by bidding, and the highest bids will get units. Everyone will pay the same price (in tokens) for units when the auction ends. You cannot bid more tokens than you have. The total number of units will be the same each time we repeat this auction.
(7). We will play auctions in this order: buy-sell/bid-only/buy-sell/bid-only. Earnings are cumulative.
(8). The **second** bid-only auction will be a single round auction for the movie tickets. Players can bid for these tickets from their accumulated token balances (converted into dollars). Players who were given tickets will receive the sales price of their tickets as cash earnings. Thus, a player endowed with a pair of tickets may choose to buy those tickets back (net zero cash earnings = spent cash equals earned cash) or not buy them back (positive cash earnings).
(9). The auctions will end at a random point between 60 and 90 s. The ticket auction will end at a random point between 120 and 150 s.
(10). We will play one practice round for each auction type so you can get familiar with the auction layout. After the practice rounds, I will answer your questions. Then we will begin.

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