The Role of Instream Flows in a Water Market: 
Using Experimental Economics to Address 
Environmental Issues

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1. INTRODUCTION

When water was first diverted for offstream use in the western United States, the economic value of instream flows was minimal and typically did not compete with mining or agricultural diversions. There was little concern about maintaining instream flows, let alone who owned the rights to these flows. Environmental awareness was virtually nonexistent. Hence, as the system of Western water rights evolved under the doctrine of prior appropriation, these rights were predicated on beneficial, consumptive use, and virtually ignored instream uses. Reserving water rights for the maintenance of instream flows was not usually recognized as a beneficial use of water, and therefore had little or no legal standing. Only recently, as the demand for instream flows has increased and created a potential conflict with consumptive uses, have states begun to recognize the importance of protecting instream flows and to implement policies for their maintenance.

On those streams that are fully appropriated, additional instream flows must come from either a reduction in aggregate consumptive use or a shift in the locations at which certain quantities of water can be diverted (this would most likely involve attempts to induce water diversions and consumption at locations further downstream). Any attempts to guarantee minimum flows through specific stream reaches would also restrict the transferability of a water right. In a market characterized by bilateral negotiations, the presence of minimum instream flows, combined with a lack of coordination among the many buyers, sellers, and affected third-parties, can result in both high transaction costs and high transaction risks, and rarely leads to efficient outcomes.\(^1\) The advantage of a computer-assisted market, such as the one tested in this paper, is that it combines the information and

\(^1\) By transaction costs, we mean those costs associated with locating a trading partner, getting transfer approval, coordinating the actual water conveyance, etc. By transaction risks, we mean the possibility that after a trading partner has been located and a deal negotiated, the transfer will not occur for reasons beyond the control of the parties to the transfer (e.g., transfer request rejected due to environmental impacts, no conveyance capacity available, etc.).
incentive advantages of decentralized ownership rights with the coordination advantages of centralized processing – which is a particularly attractive feature, especially when external affects need to be incorporated into the market allocation mechanism.

The research reported in this paper uses laboratory experiments to design and test alternative institutional structures that attempt to incorporate instream flow demands into a computer-coordinated water market. Of particular interest are those situations in which accomplishing environmental objectives does not necessarily require a reduction in the supply of water available for consumptive use. (Those cases in which environmental demands are met through a supply reduction are essentially the same as adding an additional consumptive user at a particular node). The usufructory nature of water rights means not only that multiple parties can derive benefits from the same units of water, but also that, unlike property rights for most other private goods, these diverse third-party interests are all protected. This rather unique property rights structure can create complications for any institution that facilitates water transfers.

Addressing the problems associated with instream flows is essential to the development of voluntary water transfers as a means of allocating water in California, and throughout most arid regions of the world. Failure to adequately account for these impacts could dramatically reduce the economic benefits of voluntary water transfers. Computer-coordinated markets have the potential to account for these third-party impacts, and this research analyzes institutional structures that are designed to account for such issues. This paper proceeds as follows. Section 2 provides some background on instream flows and the use of experimental economics. Section 3 outlines the experimental methodology. Section 4 presents some preliminary results and Section 5 summarizes the paper.
2. BACKGROUND

2.1. Instream Flow Protection

Instream flow protection has been accomplished in a variety of ways in the western United States (see Anderson and Snyder, 1997, for details on some of the different approaches). Although the specifics of the state policies can vary significantly, they generally involve some form of centralized, government control over stream flows, typically as minimum instream flow requirements. Because instream flow protection is inextricably linked with attempts to facilitate voluntary, compensated water transfers, this raises questions about the appropriate institutional structure for providing these flows in a market-oriented environment.

In the context of water market development, the “problem” of instream flows stems, at least in part, from the nature of the property rights to water. Most Western water rights are usufructory, or usage rights. Usufructory rights provide the holder with the right to use the water, but not actual ownership of the water itself. These rights are usually defined by the time and place of diversion, as well as the type of use (e.g., agricultural, urban, etc.), and a change in any of these conditions of use constitutes a water transfer. Although the water right is not possessory, the courts have still recognized water rights as a legitimate property right (McCormick, 1994). However, most states, including California, have a “no injury” requirement before any water transfer can occur, giving third-parties legal standing in the transfer approval process whenever a transfer of water from its present point of diversion could adversely affect some of these other activities. This is unlike a possessory right in which these other uses may have no legal standing.

In order for a market to allocate water efficiently, these external impacts must be incorporated into any transfer decision. There is some empirical evidence which suggests that environmental demands for instream flows have an economic value that is commensurate with traditional consumptive uses, at least for specific case studies (Daubert and Young,
1981; Loomis and Cooper, 1990; Sanders, et al., 1990; Loomis and Creel, 1992; Booker and Young, 1994). Hence, the question is not whether instream flows have an economic value, but whether these demands can be translated into property rights that will encourage the development of an efficient water market.

One potential solution is to facilitate environmental acquisition of either water rights or instream flow rights. Environmental participation in a water market is certainly not a new concept. Colby (1990a), DWR (1994), Simon (1997), and Johnson and Snyder (1997) provide details on a number of instances throughout the West in which a private organization or government agency has acquired water for environmental purposes. In California, there have also been a number of proposals to use markets as a low cost means of meeting environmental objectives (Thomas et al., 1997; Miller, 1997; Fullerton and Miller, 1997). The specifics may vary, but these proposals essentially recommend the creation of an independent, non-government, agency that would be responsible for managing environmental quality. One of the research question this paper seeks to address is how this environmental trustee can be brought into the market and how his participation affects the market outcomes when compared to an institution with minimum instream flow constraints and no environmental participation.

Although there is movement towards some form of environmental participation in a water market, there is still considerable debate about whether and how water markets can be structured to incorporate instream flow demands. One frequently expressed concern focuses on the public good nature of instream flows. When multiple agents independently derive benefits from a good, and they cannot be excluded from doing so, there is no economic incentive for these agents to voluntarily contribute to the provision of the public good.

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2 A water right is the right to divert water from the stream. An instream flow right is simply a right to a specified quantity of water flowing through a particular stream reach; these rights are non-consumptive.
Without these contributions, a water market will tend to underprovide these goods relative to the socially optimal allocation, even if private agents are permitted to acquire instream flow rights (Colby, 1990a; Wahl, 1990). Griffin and Hsu (1993) demonstrate this theoretically. Moreover, if some form of instream flow rights were created, there may be the potential for the holder of the right to extract rents from any upstream transfers (Livingston and Miller, 1983). These issues have sparked a debate that focuses on the implications of public versus private acquisition of water to provide instream flows. The argument in favor of government control is rooted in the assumption that instream flows are a public good and cannot compete in a market with consumptive uses. On the other hand, proponents of private ownership focus on the usual failures of state intervention, such as a lack of incentives to respond to price signals and the potential for rent-seeking behavior (Huffman, 1983; Anderson and Johnson, 1986; Anderson and Snyder, 1996). Wahl (1990) comments that the optimal solution probably rests somewhere in between these two extremes, with private acquisition of instream flows complementing the actions of a government agency.

California’s Department of Water Resources, which brokers the state’s drought water banks, is also somewhat leery of the ability of a “theoretical free market” to adequately address third-party impacts and argues for a centrally-managed allocation mechanism. In their Environmental Impact Report for a permanent State Drought Water Bank, DWR expresses concern that a free water market would fail to adequately account for these diverse interests:

A theoretical free market in California is probably not workable…Any water transfer market will need to address environmental, economic, and social impact issues through some combination of governmental requirements and voluntary limitations (DWR, 1993, p. 190).

The market that DWR envisioned when making this statement would consist of bilateral negotiations between buyers and sellers, in which case it is probably reasonable to assume that external impacts would receive inadequate consideration.
The advantage of a computer-assisted market, such as that used in this research, is that these third-party issues can easily be incorporated into the allocation process. This can be accomplished in a variety of ways; the research question is what the market impacts would be for these alternative institutions. In this paper, we analyze various property right arrangements and institutional structures in which this environmental trustee is able to participate. By developing a market mechanism that adequately accounts for these instream flow demands, such an institution is less likely to introduce new sources of conflict into California’s “water wars.”

2.2. Experimental Economics and Environmental Management Issues
The use of private property rights to address environmental and natural resource issues is becoming a more common policy instrument, e.g., water markets, marketable pollution permits, and individual transferable quotas (ITQs). In theory, such institutions can achieve environmental objectives or protect the resource at a lower social cost than the more traditional reliance on government imposed standards. However, different institutional rules can have a tremendous impact on the actual level of efficiency achieved by these environmental compliance markets.

By analyzing alternative water market institutions in an experimental context, we are to test these new institutions in a controlled setting before they are actually implemented.

Although the theoretical benefits of these environmental compliance markets are well-established, the actual design and implementation of such markets are less so. In the context of environmental and natural resource management, two strands of research that have utilized laboratory experiments are marketable pollution permits and common-pool resources. Cason and Plott (1996) test the EPA’s auction rules for trading sulfur dioxide allowances and find that its performance is subpar relative to a uniform price call auction.
Cason and Gangadharan (1998) report the results from a series of experiments designed to
test several features of a tradable emission permit program in Southern California. Ishikida,
et al. (1998) study the potential for using a computer-coordinated market to address the
combinatorial nature of the demand for these smog permits in the Los Angeles area. Walker
et al. (1990), Walker and Gardner (1992), Hackett et al. (1994), Hackett and Walker (1995),
and Gardner et al. (1997) explore various issues related to the management of common-pool
resources.

Experimental methods have been also applied to evaluate the performance of
computer-coordinated markets in several industries. These electronic markets can often
reduce the search costs and coordination problems that typically arise in complicated
environments, thereby facilitating trades that may not have otherwise been transacted and
increasing overall market efficiency. Testing proposed institutions, such as a computer-
coordinated water market, in a laboratory setting yields a formal and replicable system for
analyzing alternative market structures before they are actually implemented. These market
designs can be developed and tested in the laboratory during years of sufficient water to
simulate drought conditions. If the results are positive, such a market could be implemented
during years of water scarcity.

One of the earlier applications of ‘smart’ market technology was motivated by the
question of how one might design an auction market for airport runway access rights to
complement the deregulation of the airline transport industry. This led to the development of
the experimental combinatorial auctions (Grether et al., 1982; Rassenti et al., 1982). In a
combinatorial market, agents often submit contingent bids for complex packages of goods,
the individual components of which are less valuable if consumed independently. In the case
of runway access, for example, the right to take off from one airport at a particular time is
valuable only if the plane has a corresponding landing right at the appropriate time for the destination.

Subsequent applications of the computer-assisted market technology for composite goods have included natural gas pipelines and electric power networks. These electronic markets eliminate many of the coordination problems that characterize these markets – which is a particularly attractive feature for water markets, especially in the presence of third-party impacts. The structure of these network industries, consisting of producers connected through pipelines to consumption nodes, closely parallels the physical features of water networks. In these computer-assisted network flow problems, agents do not have to find a trading partner. They must simply express their location specific willingness-to-pay (or willingness-to-accept) for the commodity. Since the reported individual demand (supply) functions need not, and generally do not, correspond to the true willingness-to-pay (willingness-to-accept), the important research question is whether incentives to under-reveal demand (supply) have any significant impact on the market outcomes. Natural gas and electric power experiments demonstrate very high efficiency because, although intramarginal units are greatly under-revealed, marginal units are not. These conditions are all that is required to achieve efficient allocations in uniform price market mechanisms (McCabe et al., 1989, 1990, 1991).

3. METHODOLOGY

3.1. Objectives

The objective of this research is to extend the analysis of computer-assisted water markets discussed in Dinar et al. (1998) to include demands for instream flows. The basic hypothesis

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3 A composite good is a collection of well-defined constituent goods and services, such as the purchase and delivery of water.
is that active environmental participation in the market should result in more efficient water allocations than an institution in which these demands are reflected in binding constraints on water transfers. However, given the likely nature of environmental participation, there is the potential for strategic behavior that could erode some of the possible gains from exchange. The research question, then, focuses on market design and the ability of alternative institutional structures to incorporate instream flow demands efficiently. In addition to market efficiency, we are also interested in the distribution of surplus, price discovery, and market volatility.

3.2. Experimental Design

In this water market experiment, we use a version of the computer-assisted Uniform Price Double Auction (UPDA) detailed in McCabe et al. (1993) and applied to water markets by Dinar et al. (1998). As a price mechanism, UPDA’s distinguishing feature is that all accepted bids to buy are filled at a price less than or equal to the lowest accepted bid price of buyers – a price that just clears the market by making the total number of units sold equal to the number purchased. Similarly, all accepted offers to sell water are filled at a price greater than or equal to the highest accepted asking price of sellers.

We report the results from 12 experiments that were divided into 3 treatments and generated 100 market observations per treatment. The treatments are discussed in more detail in section 3.3. Subjects were recruited from the participants in the experiments reported in Dinar et al. (1998), meaning that all subjects had participated in at least three prior water market experiments using the same software (but different experimental design). Before the start of the experiment, subjects were given five dollars for showing up on time. At the end of the experiment, subjects were paid their performance-based earnings in cash; these profits ranged between $13 and $41.
All the experiments were run in the Economic Science Laboratory at the University of Arizona using a Windows-based application designed specifically for these water market experiments. This software (1) allows subjects to submit node-specific bids and asks, (2) displays the water network along with the tentative market price and quantity at each node, (3) informs subjects about which of their bids (or asks) were tentatively accepted at each node and computes profits, (4) provides market history data reporting the results of prior trading periods, (5) enforces the rules which define the institution, and (6) calculates the optimal resource allocations.

In this series of experiments, subjects were only active as buyers or environmentalists. Transmission was costless and the water was injected into the network by a computer robot that simply revealed its supply costs. Buyers' profits were calculated as the difference between the induced resale values given to the subjects and the actual price paid for the water in the market \(i.e.,\) consumer’s surplus). The environmental agent derives a benefit from any water flowing past his location – regardless of whether he contributes to its provision. The means through which he can participate in the market defines the three different treatments.

Each spot market experiment lasted about two hours and was divided into a pair of five-minute practice periods followed by 25 independent three-minute trading periods. The data from the practice periods was discarded. To minimize end-game effects, subjects were not told when the experiments would terminate. Tables 1 to 3 report the empirically-derived induced supply and demand step functions given to every agent for each of their locations in the network. The derivation of these parameters is discussed in Dinar et al. (1998). These induced values are used to motivate subjects in a manner that is consistent with that observed in the economy. These values are only known by the experimenter and the individual. The computer is also unaware of these values; it uses only the submitted bids and asks in determining the equilibrium allocations.
During each three-minute trading period, subjects can submit location-specific bids as frequently as they wish, subject to an improvement rule which required that each new bid to buy water must be at a higher price or increased quantity than any previous submission. Submitting a bid is costless. These price-quantity submissions represent the maximum price that the individual is willing to pay for the specified quantity of water. These submissions could be divided into as many as five separate price-quantity steps. After each new submission, the computer instantaneously recalculates the allocations and reports the new equilibrium prices and quantities for each node. Each subject knows the price and total quantity at each node in the network, as well as his or her market share, but does not know anything about the individual allocations of the other subjects. These allocations are tentative until the market is called after three minutes, at which time they become binding contracts, profits are computed, and a new period begins.

This computer-coordinated auction market maximizes total gains from exchange based on the submitted bids and offers, and determines allocations and nondiscriminatory prices at all nodes and conveyance channels. For any set of submitted bids and offers, solving the following linear programming problem maximizes the realized surplus in the network:

\[ \text{Maximize total surplus:} \quad - \sum_i c_i f_i + \sum_{env} f_i \]

subject to:

\[ \text{balance of flow:} \quad \sum_{i \in S_k} f_i = \sum_{i \in E_j} f_j \quad (\forall \text{ nodes } j); \]

\[ \text{conveyance capacity:} \quad d_i \leq f_i \leq u_i \quad (\forall \text{ arcs } i). \]

Each arc \((i)\) in this formulation represents one bid or offer. If a buyer makes a two-part bid, then it is represented by two parallel arcs. Two-part offers by sellers are represented similarly. Thus, each bid or offer is represented by the vector \((s_i, e_i, d_i, u_i, c_i)\) with \(s_i\) being its starting node, \(e_i\) its end node, \(d_i\) the least permissible flow on that arc, \(u_i\) the greatest...
permissible flow on that arc (determined by the bid or offer quantity entered), $c_i$ the bid value or offer price per unit of flow on that arc (bid values are negative costs) and $env_i$ is the environmental bid for flow along that arc. The flow on arc $i$ is $f_i$, $S_j$ is the set of arcs which begin at node $j$, and $E_j$ is the set of arcs which end at node $j$. Note that constraint set [2] maintains the balance of flow at each node $j$. Constraint set [3] ensures that the flow on each arc does not exceed the stated lower or upper bounds.

3.3. Network Description

The network used in the experiments is shown in Figure 1. This network provides a simple representation of the water flow in California, or most any river system in which instream flows have value. This network has two river systems, only one of which contains a benefit for instream flows. The other system is environmentally benign. There are multiple heterogeneous buyers of water at each of three locations. Upstream node $B_{u1}$ is located along the environmentally benign stream, and upstream node $B_{u2}$ is located along the environmentally sensitive stream. These two systems converge at the downstream consumption node $B_d$. Each buyer is given a multi-step schedule with his or her respective resale values of water. This information is private. For each unit purchased in the market, buyers earn the difference between the resale value and the market price. These schedules are provided in Table 1.

With this network design, buyers at the two upstream nodes can only acquire water from a single source, but downstream buyers can be supplied from both sources. This structure allows us to evaluate the potential impacts when some sources of water yield an instream flow benefit (supply node $W_2$), and other sources do not (supply node $W_1$). Water is injected into the network at an increasing marginal cost by a “robot” that simply reveals these costs and does not engage in any strategic behavior. These costs are listed in Table 2.
Between the two buyer nodes is the single environmental trustee, at E₀, who values streamflow between nodes B₂ and B₄. The objective of this trustee is to maximize environmental quality. For the purposes of this research, we assume that maximizing an anadromous fish population is a reasonable proxy for this objective, and that the fish population is an increasing function of instream flows. In all three institutions, the environmental trustee has a downward-sloping demand for instream flows as shown in Table 3. Note that the instream flows are identical to the quantity of water flowing from source W₂ that is consumed by the downstream buyers (B₄). The means by which the trustee can influence the flow at E₀ is the primary difference among the three institutions.

There are three environmental property right simulations that were performed in the laboratory: (1) a water market with minimum instream flow requirements, and no environmental participation; (2) a water market without any environmental constraints, but the environmental trustee is endowed with a budget with which to provide instream flows; and (3) a water market in which the environmental trustee has transferable property rights to the instream flow constraints. These are roughly parallel to institutions in which the environmental trustee (1) has no power to influence instream flows; (2) can increase flows by subsidizing downstream consumption; and (3) can tax upstream transfers, thereby increasing the quantity of water diverted downstream.

1). *A water market with environmental standards, but no environmental participation*

This scenario is closest to the existing institution and is used as a baseline against which the alternatives can be compared. Consumptive water users are free to trade, subject to minimum instream flow requirements. The environmental trustee does not participate in this market. This institution guarantees a minimum level of environmental quality, but there is no mechanism for acquiring additional water to increase instream flows.
2). The environmental trustee induces additional instream flows by subsidizing downstream consumption.

This institution is analogous to a situation in which the instream flow constraints are not sufficient to meet environmental demands and the trustee is responsible for inducing supplemental flows. Without environmental participation, the equilibrium market allocation will not reflect instream flow values (Griffin and Hsu, 1993). By contributing to the cost of providing instream flows, the environmental trustee effectively subsidizes downstream consumption, thereby inducing increased flows. However, as long as the downstream buyers acquire water from source $W_2$, the environmentalist will benefit from at least some instream flow, regardless of his market activities, creating an incentive to free-ride. Note that if there were multiple environmentalists active in the market, this would only exacerbate the free-rider problem.

This situation loosely parallels an ongoing debate in California about the use of water dedicated to instream flows. Consumptive users claim that once the water has fulfilled the instream flow demand, the water is available for diversion further downstream. Environmentalists, on the other hand, essentially argue that these environmental flows cannot be diverted and should flow into San Francisco Bay. If the property rights are well-defined, the potential exists for both groups to negotiate an allocation that could benefit them both.

3). The environmental trustee has rights to existing environmental standards.

Another approach to incorporating the environmental demands into a water market would be to give the environmental trustee a transferable property right to instream flows. In theory, if the marginal private gain resulting from any transfer that would violate the instream right exceeded the marginal environmental damages incurred by the trustee, relaxing the flow
constraint could result in a social welfare gain if the environmental trustee were compensated for his losses. This potential to lease instream rights provides some added flexibility to the market by forcing the environmental trustee to evaluate the opportunity costs associated with holding these instream rights. If the market is perfectly competitive, the price received by the environmentalist will be the optimal Pigouvian tax on upstream consumption.

However, note that unlike the cotenancy arrangements discussed in Rassenti et al. (1994), it is not feasible to have cotenant suppliers of “instream flow reductions.” If a single agent has the transferable private property right to the last $Q_{min}$ units of flow in the river, another agent cannot simultaneously hold an exclusive instream flow right to any quantity of flow less than or equal to $Q_{min}$. This unique situation creates the potential for strategic behavior on the part of the environmental trustee because he is the sole supplier of this good. By withholding the supply of “instream flow reductions,” the trustee can attempt to extract supra-competitive rents. Although such an allocation may increase efficiency relative to the baseline (i.e., rigid minimum flow constraints), it is not an economically efficient outcome.

4. PRELIMINARY RESULTS

4.1. Market performance

There are three measures of market performance that we discuss in this section: efficiency, distribution of surplus, and volatility. After defining the terms, we use these criteria to evaluate the performance of the water market.

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4 Software problems forced a postponement of some of the experiments. As of this writing, we have only completed the experiments for which the environmental trustee pays to supplement instream flows. The remaining experiments are scheduled for the end of May and results will be presented at the conference. Until the other experiments are completed, we cannot really make any strong empirical claims about the performance of this market or how it compares with alternative institutions.
Each buyer of water, \( b \), located at node \( j \) has a resale value, or benefit, schedule \( B_{bj}(Q_{bj}) \). In equilibrium, all buyers \( b \) at node \( j \) pay the same market price, \( P^*_j \), and each buyer \( b \) earns a profit of:

\[
\Pi^*_bj = B_{bj}(Q^*_bj) - P^*_jQ^*_bj,
\]

where \( Q^*_bj \) is the equilibrium quantity of water delivered to buyer \( b \) at node \( j \). Aggregate buyer earnings are:

\[
\Pi_{Buy}^* = \sum_b \sum_j \Pi^*_bj.
\]

Similarly, each seller of water, \( s \), located at node \( j \), has a cost schedule \( C_{sj}(Q_{sj}) \), and in equilibrium all sellers \( s \) at node \( j \) receive the same market price, \( P^*_j \), and each seller \( s \) earns a profit of:

\[
\Pi^*_sj = P^*_jQ^*_sj - C_{sj}(Q^*_sj).
\]

Aggregate seller earnings, \( \Pi_{Sell}^* \), are the sum of the individual earnings of all sellers. The environmental agent, \( e \), located along arc \( i \), derived a benefit from any water that flows past his location \( B_{ei}(Q_{ei}) \), and in equilibrium, his per-unit contribution to providing instream flows is \( P^*_i \), yielding a profit of:

\[
\Pi^*_ei = B_{ei}(Q^*_ei) - P^*_iQ^*_ei.
\]

What distinguishes the environmental agent in equation [7] from a buyer in equation [4] is the non-consumptive nature of the environmental benefit function. Unlike water purchased for consumptive use, water used to provide instream flow benefits is still available for use further downstream. Moreover, if water acquired by downstream buyers flows past the environmental agent’s location, the environmental agent will benefit from these flows regardless of whether he contributes to the provision of the flows. What the environmentalist can do, however, is offer to subsidize downstream consumption of water from
environmentally beneficial sources, thereby increasing the quantity of water flowing instream.

Note that the realized equilibrium values, denoted by the \( ^* \) superscript, are calculated by the computer based on the submitted bids and asks of each agent. As experimenters, we also know the true supply and demand schedules and can use these to calculate the competitive equilibrium prices, allocations, and earnings for each subject. The competitive equilibrium values will be denoted by replacing the superscript \( ^* \) with the superscript \( ^{ce} \). Because the competitive equilibrium maximizes the possible gains from trade, we use this as a baseline against which the realized market outcomes can be compared.

Efficiency measures the ability of the market to extract all of the potential gains from trade. It is the share of potential surplus realized by the market:

\[
EFF = \frac{\Pi_{buy}^* + \Pi_{sell}^* + \Pi_{env}^*}{\Pi_{buy}^{ce} + \Pi_{sell}^{ce} + \Pi_{env}^{ce}} \in [0,1].
\]

Similarly, the efficiency of a particular subject can be calculated as the ratio of that subject’s actual earnings to his or her earnings in the competitive equilibrium. The competitive equilibrium results in an allocation that maximizes the total possible surplus, so a perfectly competitive market will be 100 percent efficient. Table 4 lists the market efficiencies achieved in each of the experiments computed as an average across all periods.

During the first eight periods, the market is quite unstable and inefficient as subjects attempt to discover an equilibrium. During this time, the market efficiency averages only 79 percent, prices tend to be below the competitive equilibrium, and quantities traded are volatile. After this discovery phase, the market stabilizes and efficiencies averaged 96 percent, which is consistent with those observed in similar network experiments (McCabe et al., 1989, 1990, 1991). At nodes B_d, B_u1, and W_1, prices converged to the competitive equilibrium in the later periods. The mean prices at nodes W_2, B_u2 and E_0, all of which are on the environmentally sensitive stream, were below the competitive equilibrium, even in the
later periods. (See Figures 2 and 3 for charts with price and quantity time-series observations). The primary driving force behind this result appears to be the sub-competitive contribution of the environmental agent to the provision of the public good (an average of nine experimental dollars per unit, rather than 15). The low contribution of the environmental agent effectively reduces the demand downstream (node B_d) for water from W_2, which translates into a lower price for the seller at W_2. The lower price of water at W_2 should benefit upstream buyers (node B_u2) via a lower price.

The environmental contributions also have a high variance, even in later periods. This instability appears to be the primary cause for the volatility in the quantity traded at the different locations. Note that the quantity of water supplied is stable, but the distribution of these supplies among the buyers varies significantly and depends largely on the magnitude of the environmental contribution to instream flows. Also note that the mean environmental contribution exceeds that which could have yielded the trustee maximum profits. All else equal, a contribution of three dollars with a flow of 174 units, rather than nine dollars for 215 units, would have increased his profits by about 16 percent. Thus, although we observe some free-riding on the part of the trustee, it is not complete. How is it possible that an environmentalist could be better off with reduced instream flows? Instream flows alone are not sufficient for maintaining environmental quality; investments in non-flow related projects, such as habitat improvements, are also essential. If the trustee is operating with a limited budget, he faces a trade-off between acquiring additional flows or investing in some other non-flow related project. If the marginal environmental benefit from these other projects exceeds the incremental gain from providing instream flows, the trustee may elect to forego additional stream flow and invest in these other projects.
Distribution of surplus is another measure of market performance. It measures the share of realized total surplus earned by a given individual, or group of individuals. For example, the percent of realized surplus, or profit share, of all the buyers is:

\[
SHARE = \frac{\Pi_{Buy}}{\Pi_{Buy} + \Pi_{Sell} + \Pi_{Xfr}} \in [0,1].
\]

Table 5 reports the average profit shares for buyers, sellers and the environmental trustee. Overall, when compared to a perfectly competitive market, there is little difference in the surplus distribution. There is a slight, but statistically significant, shift in surplus that benefits the environmental trustee and the upstream buyers at node B_{u2}. This shift in surplus comes at the expense of the sellers at W_{2}. Consistent with the earlier discussion on prices, the motivation for this welfare shift appears to stem from the lack of voluntary contributions by the environmental agent.

5. SUMMARY

Griffin and Hsu (1993) demonstrated that a water market which does not include instream flow demands will tend to underallocate water to the environment. However, this does not necessarily imply that permitting the acquisition of instream flows in efficient allocations. Over thirty years of laboratory evidence reminds us that, unless the institution is structured properly, it is possible that the potential benefits from environmental participation in water markets will not be realized. A successful market-oriented approach to water management in California, or any arid region, must account for instream flow values. Failure to do so may result in an underallocation of resource to ecosystem preservation, and would warrant a more centrally-managed approach that may be slow to adapt to a constantly changing environment.

In this paper, we test a computer-assisted uniform price double auction that is designed to account for instream flow values. Preliminary results suggest that there may be efficiency gains from environmental participation, but further tests are necessary before any
conclusive observations can be made. Initial results from the first of a series of experiments indicates that in a computer-coordinated uniform price double auction, environmental acquisition of instream flows can lead to efficiency gains, but may yield a more volatile market.

Finally, an experimental approach certainly has great promise for institutional testing and market familiarization, and can probably form the basis for an operational market. This may have significant advantages over conventional bilateral markets in that it may save society costs associated with actual trial and error in the stage of evaluation and establishment of the market. Initial water markets are likely to be thin and require low transaction costs to become established. Properly designed computer-coordinated markets can have significant advantages under these situations.
REFERENCES


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Table 2. Induced Supply Schedules

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Table 3. Induced Environmental Demand Schedule

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Table 5. Distribution of Surplus

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Figure 1. The Location of Agents Along the Watercourse

W1: Water Source

Bu1: Upstream Diverters

E0: Environmental Trustee

Bd: Downstream Diverters

W2: Water Source

Bu2: Upstream Diverters
FIGURE 2. PRICES AND QUANTITIES AT BUYER LOCATIONS
Institution 2: Environmental Trustee Acquires Supplemental Instream Flows

Price at Node Bd

Quantity at Node Bd

Price at Node Bu1

Quantity at Node Bu1

Price at Node Bu2

Quantity at Node Bu2
FIGURE 3. PRICES AND QUANTITIES AT ENVIRONMENTAL AND SELLER LOCATIONS
Institution 2: Environmental Trustee Acquires Supplemental Instream Flows