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# Mechanisms for Addressing Third-Party Impacts Resulting from Voluntary Water Transfers

University of California Water Resources Center
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## Abstract

This research uses laboratory experiments to test alternative water market institutions designed to protect third-party interests. The institutions tested include taxing mechanisms that raise revenue to compensate affected third-parties, and a free market in which third-parties actively participate. We also discuss the likely implications of a command-and-control approach in which there are fixed limits on the volume of water that may be exported from a region. The results indicate that there are some important trade-offs in selecting a policy option. Although theoretically optimal, active third-party participation in the market is likely to result in free-riding that may erode some or all of the efficiency gains, and may introduce volatility into the market. Fixed limits on water exports are likely to result in a more stable market, but the constraints on exports will result in lower levels of social welfare. Taxing transfers and compensating third-parties offers a promising balance of efficiency, equity and market stability.

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# Introduction

Despite the comparatively short experience of California with water markets, voluntary transfers are now regarded as a central instrument in balancing and reallocating the changing demand and supply for water in the state. However, until it can be demonstrated that a water market institution is capable of protecting environmental and third-party property rights, voluntary water transfers will not realize their full potential as an integral part of California's water management strategy in the 21st century.

This research focuses specifically on policies and institutions designed to protect the rights of third-parties, in particular rural communities that depend upon irrigated agriculture for their livelihoods but are not party to the market transaction. The importance of third-party impacts is underscored by the numerous proposals that have been put forth to protect affected third-parties. Most of these proposals involve some form of restriction on transfers; these include a tax on transfers, a limit on the quantity of water that can be transferred out of the district, or a limit on the amount of land that can be taken out of production. Another alternative, proposed by the Model Water Transfer Act (Gray, 1996), is to decouple transactions and compensation through the establishment of a fund from which third-party claims would be paid.

This project uses economic experiments to test the implications of a tax on transfers to compensate third-parties, similar to that proposed by the Model Water Transfer Act (Gray, 1996).[1] During droughts, rapid approval of *short-term* transfers is critical as there may not be adequate time for a lengthy transfer review process. In the experiments, a tax is imposed on all transfers based on *projected* third-party damages and placed into a third-party compensation fund. Actual damages are not known until after all transfers have been executed. At the end of the water year, third-parties can file claims for compensation from the fund, and all third-parties are fully compensated for damages. If there is any revenue remaining in the fund after all third-parties are compensated, the residual funds are carried over to the next water year, resulting in a lower tax rate in the next year. Similarly, if there is insufficient tax revenue to fully compensate all third-parties, the fund goes into a deficit and will make up for the shortfall by raising the tax rate in the next year.

In theory, this taxing mechanism is not optimal in terms of either efficiency or equity, essentially because those trades that generate the third-party impacts may not be paying the full marginal damages. Instead, these costs are shared by all water users, not only in the current water year, but possibly by those in past or future years. An alternative is to create some form of tradable third-party property rights. In theory, since third-parties best know their own circumstances and willingness to trade, such a mechanism could achieve efficient outcomes. The advantage of economic experiments is that we can formally test these theories in a controlled setting. Some of the key results are summarized below:

- Although some form of third-party participation in the market may be theoretically optimal, it is prone to strategic behavior and free-riding that may erode most, if not all, of the efficiency gains.

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[1] See Appendix A for a brief discussion of experimental economics.

- Taxing transfers to compensate victims as described above may not be a theoretically optimal mechanism, but the market still yields highly efficient and stable outcomes, and is more flexible than fixed limits on water transfers. Although further research is necessary, this mechanism is a promising means of ensuring that third-parties are compensated.

One important potential disadvantage to the tax mechanism is the threat of bankruptcy. In a prolonged drought, it is possible that the compensation fund may run a deficit for a number of consecutive years. If there is a deficit in a given year, the tax rate in the following year would increase to make up for the shortfall. However, if there are too many tax increases without an infusion of additional capital, it is conceivable that future tax rates could escalate to a level that effectively makes transfers prohibitively expensive. It is likely that minor modifications of the mechanism we tested could minimize the threat of bankruptcy. One possibility that we did not test would be to spread any revenue shortfalls over multiple years, rather than a single year. This would reduce the magnitude of the year-to-year tax rate adjustments.

## Objectives

This research uses laboratory experiments primarily based on policy options that have been proposed by government agencies and academics to address third-party impacts. It is critical that a mechanism designed to protect third-parties be not only efficient and stable, but politically acceptable to all parties involved. This means a viable water market institution must incorporate the third-party demands into the water allocation mechanism.

The traditional approach to mitigating negative externalities associated with water transfers is to impose some form of command and control regulation. This is usually in the form of minimum instream flow constraints or limits on the volume of water that may leave a region. However, by placing limits on the quantity and type of transfers that can occur, the resulting allocation is usually less than efficient. Moreover, command and control regulations are often slow to adapt to changing needs.

This research does not test a command and control type treatment. Murphy (1999) tested a water market institution with environmental demands for water, but no active participation by environmental interests. In other words, buyers and sellers were allowed to trade water freely, but there were minimum instream flow requirements that could not be violated. This guarantees a maximum level of damages but there is neither an incentive to improve environmental quality nor a mechanism to accept compensation for a decrease in flows. This treatment produced highly competitive outcomes and realized the maximum gains from trade given the constraint. Although these minimum flow experiments were highly efficient and showed almost no volatility, the actual level of total surplus was lower because of the minimum flow constraints. Murphy (1999) demonstrated that by allowing these constraints to be relaxed in exchange for compensation, total surplus and environmental quality can be improved.

The research of Murphy (1999) is important to note because incorporating environmental benefits into the market has many similar characteristics to incorporating third-party values. Both environmental and third-party benefits can be classified as non-consumptive uses. A non-consumptive water user is anyone who derives a benefit from the water without actually consuming the water. For example, water flowing instream may provide environmental benefits, and water consumed in an agricultural region may provide third-party benefits such as employment to farm workers. Since the minimum flow experiments in Murphy (1999) are similar to a restriction on the quantity of water that may leave an agricultural region, we can compare the outcomes of the third-party mechanisms to these minimum flow experiments.

The following sections present and analyze the three different institutions designed to incorporate third-party impacts that were tested in this research. In all three institutions, we assume that third-parties derive a benefit from water consumed in their region. Higher levels of water consumption imply increased agricultural activity and hence higher levels of employment and other economic activity related to agricultural production. Similarly, exporting water out of a region generates third-party damages. The first treatment is to allow third-parties to act as buyers in the water market. The second treatment is an imposition of a per unit tax on all water trades and the last treatment imposes a revenue tax on all water trades.

### *Alternative 1: Third-parties as Buyers in the Water Market (3PBuyer)*

The first alternative tests a market structure which allows third-parties to actively participate in the water allocation process. This system is similar to the design by Murphy (1999), in which an Instream Flow District was created as a means to give instream flow values representation in the actual market. This treatment allows third-parties to participate in the market but does not give them property rights to water. Essentially, the third-parties act as buyers in the market and bid for water to supplement the existing quantities consumed in their region. By contributing to the provision of the water, they have the ability to increase the quantity of water in their location. This may be beneficial for them to do this since more water in their region means a higher employment rate and more economic growth. Although this is probably not the most politically viable alternative because it provides no regulatory protection of third-party interests, it does provide a valuable benchmark for testing mechanisms. In theory, if the third-parties were to behave competitively in the market, the resulting allocation would maximize total surplus (including third-party values) and would be perfectly efficient.

However, it is important to note that because of the public good nature of non-consumptive water uses, the third-parties receive a benefit for any water in their region or district regardless of whether they contribute to the provision. The theory of public goods predicts that when multiple parties independently derive benefits from a good and they cannot be excluded from doing so, there is little economic incentive for these agents to voluntarily contribute to the provision of the good. As with any public good, this may cause third-parties to under-contribute or free-ride. The results of Murphy (1999) suggest that free-riding in this type of market structure does exist, and tends to reduce market efficiency and introduce volatility into the market. Thus, although in theory this mechanism should generate the highest levels of efficiency, in practice free-riding may erode some of these efficiency gains.

### *Alternatives 2 and 3: Tax Schemes and Arbitration*

The California Model Water Transfer Act (Gray, 1996), provides the basis for the next two alternatives. Section 505 of this Model Act states that water sellers must post a security deposit of five dollars per acre foot of transferred water which serves as a bond from which third-parties who are damaged by that particular water transfer can be compensated. In Section 506, the procedures and guidelines for third-party compensation are outlined. Under the Act, all short-term water transfers are allowed to occur. At the end of the water year, any victim to a water transfer may file a claim with the State Water Resources Control Board requesting a specific amount of monetary compensation along with a brief description of the damages. Copies must go to the parties to the transfer, the California Department of Fish and Game, and Supervisors of the county or counties from which the water is transferred. The Board publishes notice of the claim, and appoints a single neutral arbitrator to govern the claim. The parties to the trade must respond to each element of the claim with an acceptance or denial within thirty days. After the response has been reviewed, the arbitrator renders a binding final judgment, and provides his written opinion to the claimant, the parties to the transfer, the Water Resources Control Board, the California Department of Fish and Game, and the Supervisors of the county or counties from which water was transferred. The claimant receives a monetary award in the amount of the arbitrator's decision, and the water seller receives any proceeds from the security deposit.

In order for this proposal to perform adequately, two components are necessary: (1) a taxing mechanism to generate revenue to compensate third-parties, and (2) an arbitration mechanism through which victims can file claim for third-party damages.

***Taxing mechanism.*** When a negative externality exists, such as third-party damages, producers of an externality have no incentive to account for these damages because they only look to their own private costs. However, to achieve an efficient water allocation, all social costs, including both private costs and third-party damages must be considered. A Pigouvian tax equal to the marginal social costs is one means through which an efficient allocation can be achieved. Pigouvian taxes force the market prices to reflect the true social cost of production and producers will bear the full cost of their activities. In practice, however, it is difficult, if not impossible, to exactly predict the level of third-party damages that will accrue in a given water year. Therefore, it is impossible to know, *a priori*, the tax level that will fully account for all third-party damages. The challenge is to design a tax scheme that accounts for this *a priori* uncertainty about third-party damages. The Model Act proposes a constant five dollars per acre-foot tax. In this research, we analyze two tax schemes that adjust each year to ensure that the "third-part compensation fund" remains fully funded and does not result in either a surplus or a deficit.

***Arbitration mechanism.*** The second element necessary for the California Model Water Transfer Act is an arbitration scheme to render judgments on how the money collected from the tax is to be distributed. The proposal in the California Model Water Transfer Act relies on an arbitration mechanism to render the judgments and make decisions. Arbitration has become one of the more popular methods of dispute resolution outside the public court system. In typical arbitration systems, the negotiators are given an opportunity to settle on their own. If unable to do this, a neutral third-party arbitrator decides on a binding final award. Farber and Bazerman (1987) discuss the advantages to using an arbitration system. Arbitration ensures that a settlement is reached yet still gives the parties incentive to negotiate because there are costs associated with using the arbitrator. These costs are due to both uncertainty regarding arbitrator behavior and risk aversion of the parties. Babcock and Taylor (1996) found that the more uncertainty there was about the arbitrator, the less likely the negotiators were to use him or her. This may cause the parties to reach a settlement on their own, or to not reach a settlement altogether.

**Sidebar: Some background on arbitration mechanisms**
There are two primary forms of arbitration: conventional and final offer. Conventional arbitration is one design in which the arbitrator makes a settlement decision based on his or her best judgment of the case. Bloom (1986) explains that this may or may not take into consideration the parties' final offers to each other. He also points out that the major criticism of conventional arbitration is that the arbitrator will simply "split the difference" between the parties' final positions creating a "chilling effect" on pre-arbitration bargaining. This gives each of the negotiators incentive to take extreme positions that do not reflect their true information. In response to this criticism, final offer arbitration was developed. This method constrains the arbitrator to impose one or the other of the parties' final offers without any compromise. The parties have greater incentive to reveal private information and make more concessions during bargaining. Farber (1981) and Bloom (1986), however, both provide evidence against this "split the difference" behavior. They show that arbitrators are influenced by the offers of the parties as well as the facts of the case. In fact, they are influenced more by reasonable offers than by unreasonable offers.

DuBose and Bigoness (1987) cite both laboratory and field studies supporting final offer arbitration, and Farber and Bazerman (1989) show, empirically, that this method encourages more settlements than conventional arbitration. On the other hand, Ashenfelter *et al.* (1992) found that, in the laboratory, dispute rates were at least as high in final offer arbitration than conventional arbitration

In a "smart market," such as the one used in this research, these two types of arbitration schemes are meaningless. These arbitration schemes require that one can identify both the party that caused the damage and the victim of these damages. In the case of a single bilateral trade, we could say that the water buyer and seller of this particular transfer jointly caused the damages to the third-party. In the case of "smart markets," however, because all water allocations are determined simultaneously, the buyer and seller are decoupled and the "system" generated the externality. Therefore, we cannot utilize traditional arbitration schemes and have designed a one-sided mechanism in which third-parties can file claims to a neutral arbitrator who is responsible for managing the third-party compensation fund. At the start of the water year, the arbitrator determines the tax rate that balances *predicted* revenues and damages. At the end of the water year, the arbitrator assesses the claims and fully compensates third-parties for any damages. With perfect foresight, the arbitrator would set the tax rate such that revenues collected from water transfers would exactly equal the level of third-party damages. Therefore, at the end of each water year, the balance of the third-party compensation fund would be zero. In reality, because *predicted* third-party damages and tax revenues may not exactly match *actual* damages and revenues, it is possible that at the end of the water year the compensation fund may run a surplus or a deficit, depending upon whether revenues or damages were greater.

Clearly, in such a mechanism there are strong incentives for third-parties to over-estimate damages and file frivolous claims. It is then incumbent upon the arbitrator to determine the true damages. In this research, we avoid this incentive problem by assuming a perfectly informed neutral arbitrator. Prior to the start of trading, this computerized arbitrator has perfect information on the value of water for all market participants. Using this information, the arbitrator can calculate the tax rate which perfectly balances the willingness to pay of buyers, willingness to accept of sellers and the third-party impacts in a competitive equilibrium. What this arbitrator cannot predict, however, is how people will actually trade in the market. Therefore, the actual market equilibrium may differ from the competitive equilibrium that was used to estimate the tax rates. After trading has ceased, we assume the arbitrator knows the exact level of third-party damages and fully compensates victims. Although, in reality, this is obviously not the case, this assumption allows us to take out the role of the arbitrator and merely award exact compensation to third-parties. Awarding exact compensation is necessary because it provides a useful benchmark for analyzing tax schemes. In a typical arbitration environment, there is incentive for the parties submitting claims to overstate actual damages in an attempt to receive more than exact compensation. Problems also may arise due to biased arbitrators. By taking out the vagaries of the arbitration process, we can focus solely on the ability of the tax scheme to account for actual damages.

Two alternative tax schemes are investigated in this research: a per unit tax and a revenue tax. These are detailed in the following two sections. In both tax schemes, water sellers are responsible for collecting the tax and conveying the tax revenue to the arbitrator. This means that sellers have to include the tax when considering their costs of selling water.[2] The arbitrator places the revenue from the tax into a third-party compensation fund from which third-parties are fully compensated for any damages at the end of every water year. The following two sections will further detail how the individual tax rates (a per unit tax, and a revenue tax) are calculated and imposed. These sections will also show the theoretical impact that each has on a market design.

### *Per Unit Tax (UnitTax)*

A per unit tax is a fixed amount paid for each unit of the good traded in the market (in the case of water, this would be stated as dollars per acre-foot). This tax is independent of the prices in the market thus the tax revenue collected per unit of water does not change as prices change. Total revenue depends upon the quantity of water traded.

The per unit tax in these experiments is based on the level of damages per unit of water in a perfectly competitive equilibrium. Because the tax is imperfect (due to the difference between the actual and competitive equilibrium outcomes), there may be a tax balance from the previous year. This balance may be positive or negative. Any shortfall in the tax fund's ability to exactly compensate third-parties or any overpaid money to the tax fund will affect the tax rate in the next period. The tax rate for a given water year is determined as follows:

$$\text{Per Unit Tax Rate} = \frac{\text{Predicted Damages} - \text{Fund Balance}}{\text{Predicted Quantity}} \qquad [1]$$

where Predicted Damages are the level of third-party damages that would occur in the coming water year in the competitive equilibrium, Predicted Quantity is the total quantity of water that would be traded in the competitive equilibrium, and Fund Balance is the amount of money left over in the third-party compensation fund from the previous year. If the Fund Balance is a positive amount (because traders overpaid in the previous period relative to actual damages) then the tax rate will decrease proportional to the amount of overpaid money. If the Fund Balance is a negative amount (the tax money collected was

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[2] Although the sellers are responsible for collecting the tax, the incidence of the tax will be divided among buyers and sellers depending upon the relative elasticities of supply and demand.

not enough to compensate third-parties in the previous year) then the tax rate will increase proportionally.

### *Revenue Tax (RevTax)*

A revenue tax is a tax which is a percentage of the total revenue produced in the market. A common example of a revenue, or *ad valorem*, tax is the retail sales tax. Total revenue is simply the total quantity of water sold by a seller multiplied by the market price. For example, if there is a 10 per cent revenue tax in a given period and a seller received $3000 in revenue, then that seller would be responsible for paying $300 to the compensation fund. The revenue tax is calculated similar to the per unit tax except that it is based on revenue instead of quantity as shown below:

$$\text{Revenue Tax Rate} = \frac{\text{Predicted Damages} - \text{Fund Balance}}{\text{Predicted Revenue}} \qquad [2]$$

where Predicted Revenue is the total revenue collected by all sellers in the perfectly competitive equilibrium.

## Experimental Procedures

This research focuses on three different market institutions described in the previous section. These are:

1. Third-party as a Buyer in the water market (3PBuyer)
2. Per Unit Tax imposed on all water trades (UnitTax)
3. Revenue Tax imposed on all water trades (RevTax)

We present the results collected from eleven experiments run during the spring of 2001. Subjects for the experiments were recruited from the student population at the University of Massachusetts, Amherst. All experiments took place in a computer lab at the University where each participant sat at his or her own computer terminal. The experiments utilized the computer-coordinated water market software based out of the University of Arizona which is available over the Internet and has been used in other water market experiments. Subjects were required to commit to two days for two hours each day. The first day was used as a training day in which all participants read through online instructions and took part in several rounds of practice training. None of the data collected on the training days was used for analysis. The second day was reserved for the experiments in which usable data was collected. Participants were paid at the end of the second day and averaged $50 between the two days. This includes a $20 fee for showing up on time both days plus earnings during the experiments. Even though actual data was not collected on the training days, subjects were able to earn real money on both days. By monetarily rewarding participants, the experimenter can control preferences and market incentives that would be present in a real world scenario (Smith, 1976).
The software used for the experiments displays the entire water network to each participant on his or her computer screen and shows information about the network. The network consists of various buy nodes at which there is a demand for water, reservoir nodes from which water is sold, and canals that connect the nodes. Each participant is

assigned specific locations at which he or she is active, and is given an induced demand or supply schedule at each of these nodes. These schedules consist of five price and quantity steps and only the experimenter, the participant, and the computerized arbitrator know these specific values for water. The experiment proceeds through several periods (or water years) of trading during which each participant can submit location-specific bids to buy water and asks to sell water based on the induced demand and supply schedules. Each period lasts about 5 minutes and all participants are allowed to submit bids and asks as many times as they would like. The last submission before the period ends is the only one the computer uses. When each trading period ends, the computer takes all of the input data from all participants and applies the following optimization algorithm which finds prices and quantities at each node that maximize total surplus subject to the budget and capacity constraints (Murphy, 1999):

Maximize total surplus: $$-\sum_i c_i f_i \qquad [3]$$

subject to:

balance of flow: $$\sum_{i \in S_k} f_k = \sum_{i \in E_j} f_j \ \ (\forall \text{ nodes } j); \qquad [4]$$

conveyance capacity: $$d_i \leq f_i \leq u_i \ \ (\forall \text{ arcs } i) \qquad [5]$$

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), and $c_i$ the bid value or offer price per unit of flow on that arc (bid values are negative costs). 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 [4] maintains the balance of flow at each node $j$. Intuitively, equation [4] describes the network and defines the set of feasible trades. Constraint set [5] ensures that the flow on each conveyance arc does not exceed the stated lower or upper bounds.

Solving the linear programming problem [3]-[5] yields not only the optimal flows (and production and consumption patterns), but also the set of shadow prices, $\lambda_j$, for all nodes in the network. Since the shadow prices are marginal nodal values at which water is bought and sold, the difference in shadow prices at the start and end nodes of an arc gives us the value of the marginal unit of flow on that arc, *i.e.*, the price associated with water conveyance.

Not all bids or asks may be accepted by the computer, but the determined prices are always equal to or greater than all accepted asks from sellers and less than or equal to all accepted bids from buyers. The software displays the results immediately following each period including profits to the participants and also which bids or asks were accepted.

If a participant is active at a reservoir, this means he is a seller of water. All sellers receive an inflow of water each period which represents water from rain or melting snow. The supply schedule they see represents their costs for selling water. The costs are the lowest price for which they are willing to sell their water. All asks must follow an improvement rule which means that they must sell their lowest cost units for less than any consequent units. Figure 1 is an example of a seller bidbook which is a seller's means of entering asks in each round. The bidbook shows the seller how many units of water he has available to sell. In this example, the seller perfectly revealed his cost schedule for his 56 available units. Note that the tax rate for the period (if applicable) is displayed in the bidbook. In this round there was a 0% revenue tax. (A per unit tax would be displayed as a dollar amount and not a percentage).

Sellers earn money by selling their water at a price above the costs. Profit is calculated by the price they receive in the market multiplied by the quantity sold minus the costs as shown in the bidbook.

For both of the tax treatments, the computer system automatically adds the tax onto the sellers' asks *after* he or she submits. For example: A seller has a cost of $20 for one unit. There is a revenue tax of 10%. The seller submits an offer to sell that unit for $30 ($10 above cost). The system automatically adds the 10% tax onto the $30 offer and uses an asking price of $33 ($30 + 10% tax) when determining allocations. Suppose that when the period ends, the resulting market price is $40 for the one unit. From this $40, $4 goes to pay the tax (10% of $40), $20 is the cost for the unit, and $16 is the seller's profit.

Buyers submit bids in each round based on an induced demand schedule. The values they see are also price and quantity steps which represent the benefit they receive from using the water. Their bids therefore represent the most they are willing to pay for a given amount of water *delivered to their location.* Buyers' bids include any conveyance costs on the canals plus any taxes.

Non-consumptive users in the 3PBuyer experiments act essentially in the same way as buyers since they are bidding to buy water. The difference is that they do not consume the water and receive a benefit from the water regardless of whether they contribute to the provision or not. An example of a buyer bidbook is shown in Figure 2.

Buyers earn money by purchasing water at a price lower than the benefit they receive from consumption. Profit for them is calculated by the dollar benefit received from the water as shown in the bidbook minus the amount they paid for that quantity.

Like transportation costs, the values in the bidbook include the tax if applicable. For example: There is a $10 per unit tax in a given period of the water market, and a buyer receives a benefit of $100 for one unit of water. This is the most he is willing to pay for that one unit including the tax. The buyer submits a bid to buy one unit of water for $75. When the market closes, the resulting market price that the buyer must pay is $40. Even though the seller receives this $40, $10 must go towards paying the tax, so the seller receives a net price of $30. The buyer's profit is $100 - $40 = $60.

Third-parties do not consume the water but they still derive a benefit from any water in his or her region (or node). In the 3PBuyer experiments, the profit to third-parties is calculated by the benefit received for the amount of water allocated to their region minus any contributions offered (if any) to the provision of water in that location.

In the 3PBuyer experiments, participants were assigned the role of water buyer, water seller or non-consumptive user (third-party). In both of the tax experiments, participants were only assigned the role of water buyer or water seller since third-parties do not actively participate in the water market for these mechanisms. The demand function of the non-consumptive users, however, was utilized by the computer system in the tax treatments in order to calculate the damages that occurred. Capacity constraints and costs on the canals in all treatments were controlled by the central computer which offered conveyance and storage at marginal cost.

Each experiment was divided into 20 periods in which odd numbered periods were considered 'wet' water years and even numbered periods were considered 'dry' water years. During the dry years inflow from rain and melted snow is much less therefore supply is lower. All wet years are identical and all dry years are identical. Each year, trading occurs in a spot market. To maintain comparability of periods, the amount of water available in all wet years is always the same and the amount of water available in dry years is always the same. Water cannot be stored for use in the future.

An important specification in this research is that for the tax experiments, we assume there is no non-consumptive demand in the wet years. This means that no third-party damages occur during wet years. Third-party damages are likely to be highest in the dry years. In wet years, there is usually adequate water and little land is fallowed because of water transfers. During the dry years, it is more likely that land will be fallowed and cause economic activity to decrease in agricultural communities.

### *The Experimental Market*

The experimental water market is a simplified version of the California water network. There are two main surface water sources: The Sacramento River and the San Joaquin River. These flow into the Delta from which water flows on to Southern California cities through the State Water Project. In addition to consumption by Southern California cities, there are three agricultural centers that use the water: Sacramento Valley Agriculture, North San Joaquin Valley Agriculture, and South San Joaquin Valley Agriculture. Figure 3 is an illustration of the actual California system on which the experimental market is based.

The experimental water market which was displayed to each of the participants during the experiments is shown in Figure 4. Although the layout may look different from the actual California network, all nodes are represented and the direction of the flows are identical to Figure 3. Res-1 represents the Sacramento River. From this reservoir water may flow to Buy-1 (Sacramento Valley Agriculture) or to the Delta where it can then go on to Buy-3 (South San Joaquin Valley Agriculture) or Buy-4 (Southern California Cities). Res-2 represents the San Joaquin River. Water from this reservoir may flow to Buy-2 (North San Joaquin Valley Agriculture) or also on through the Delta to Buy-3 and Buy-4.

The market is a version of the "smart" market discussed in Murphy (1999), and Murphy *et al.* (2000), and consists of 16 roles. Each subject in the experiment may play more than one role. The two upper consumption nodes, Buy-1 and Buy-2, each have three buyers active. Consumption nodes Buy-3 and Buy-4 each consist of one buyer. There are three water sellers located at each of the two reservoirs: Nodes Res-1 and Res-2. In addition to the water being traded between the buyers and sellers, third-party impacts occur at the agricultural regions represented by nodes Buy-1 and Buy-2. There is one participant at each of these nodes who have non-consumptive demand for water in that region. Third-party damages are dependent on the amount of water consumed in the region (damages increase as consumption decreases) and are determined by the non-consumptive demand function. These two third-parties are real people in the 3PBuyer experiments, but the tax experiments do not have anyone acting in this role.

## Results[3]

The results presented in this section summarize and compare three different treatments designed to incorporate third-party demands into a water market. The first treatment, 3PBuyer, allows third-parties to actively participate in the market as a water buyer. These third-parties do not have rights to the water but they are allowed to contribute funds to subsidize water consumption in their region. By doing so, third-parties increase the demand for water in their region thereby increasing the quantity of water consumed in the region. In the second treatment, UnitTax, third-parties are not a part of the market, but an *a priori* per unit tax is imposed on all water trades in order to collect money to compensate third-parties after they have been damaged. A per unit tax is a fixed amount that is charged for every unit of water sold. The third treatment, RevTax, is also a tax scheme, but instead of a per unit tax, an *a priori* revenue tax is imposed on all water trades. A revenue tax is a percentage of total revenue that is charged on each water transfer. It is essentially the same as a retail sales tax.

Each of these treatments are analyzed by three criteria: efficiency, equilibrium prices and quantities, and distribution of surplus. In addition, the tax rate was analyzed for each of the tax treatments. This section will present and define some useful terms and then the results for each of these criteria will be presented in following sections.

In order to evaluate the performance of each market, the perfectly competitive equilibrium was used as a benchmark to compare each experiment since it is at this point that gains from trade are maximized. The competitive equilibrium is defined by the point where the induced supply and demand schedules intersect. As the experimenter, we know these induced schedules and can calculate the competitive equilibrium for each treatment. Since participants do not typically fully reveal their exact supply or demand schedules when making bids and offers, the competitive equilibrium is not necessarily the actual outcome of the experimental market. Therefore it is useful to compare the actual equilibrium to the competitive equilibrium.

For all three treatments, there is a wet year competitive equilibrium that was used to compare all wet year results and a dry year competitive equilibrium used to compare all dry year results. Because the induced parameters differ in the wet and dry years, there are obviously different competitive equilibria. In addition, for the tax experiments there are various competitive equilibria within the wet years and within the dry years. Although the induced supply and demand parameters stayed constant, the tax rate changed from period to period based on the ability of the tax rate to collect the necessary funds to compensate damaged parties (this is discussed in the previous section). In theory, if we observed the competitive equilibrium every period, the tax rate would be the same in all wet years and the same in all dry years. But, given that the actual outcomes differ, the relevant comparison is the competitive equilibrium in each period given the actual tax rate. For example if the per unit tax in a given period of the UnitTax treatment was four dollars per unit, these results must be compared to a competitive equilibrium given a four dollar per unit tax.

In all treatments profits were calculated for each participant at each node. The profit or surplus for each individual as well as total surplus in the market provides useful information in examining market criteria. Each buyer has a benefit schedule, $B_{bn}(Q_{bn})$ that he or she sees when submitting bids. This is the benefit, $B$, received by buyer $b$,

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[3] For a more detailed presentation of the results, see Mastrangelo (2001).

located at node $n$ for $Q$ units of water. At the end of a trading period, the computer calculated the results and each buyer located at the same node pays the same market price for water. This price is noted by $P_n^*$. $Q_{bn}^*$ is the equilibrium amount of water that buyer $b$ buys at node $n$. The profit for buyer $b$ located at node $n$ is therefore calculated by:

$$\Pi_{bn} = B_{bn}(Q_{bn}^*) - P_n^* \cdot Q_{bn}^* \qquad [6]$$

In the 3PBuyer experiments, profits for the third-parties are calculated similarly since they act essentially as buyers of water. The subscript $b$ in equation [6] is replaced with the subscript $p$ for third-parties. The profit for third-party $p$ located at node n is:

$$\Pi_{pn} = B_{pn}(Q_{pn}^*) - P_n^* \cdot Q_{pn}^* \qquad [7]$$

where $P_n^*$ is the price that the third-party pays at node $n$, and $Q_{pn}^*$ is the amount of water that is allocated to his region (or node).

Sellers in the market each have a cost schedule, $C_{sn}(Q_{sn})$. Each seller sees this cost schedule when making his or her offers. This function represents the cost to seller $s$ located at node $n$ to sell $Q$ units of water. All sellers located at the same node receive the same market price, $P_n^*$, for the water they sell during any given period of trading. The profit to seller $s$ located at node $n$ is:

$$\Pi_{sn} = P_{sn}^* \cdot Q_{sn}^* - C_{sn}(Q_{sn}^*) \qquad [8]$$

Aggregate earnings are calculated by summing all the individual buyers' profits to get $\Pi_{Buyers}^*$, summing the individual third-party profits to get $\Pi_{3rdParty}^*$, and summing all the individual sellers' profits to get $\Pi_{Sellers}^*$.

These experimental profits are used to calculate efficiency which is measured as the percentage of the maximum possible surplus extracted (Davis and Holt, 1993). Since the competitive equilibrium maximizes the total possible surplus, efficiency is the share of the competitive equilibrium surplus realized by the market:

$$\text{Efficiency} = \frac{\Pi_{Buyers}^* + \Pi_{Sellers}^* + \Pi_{3rd\ \ Party}^*}{\Pi_{Buyers}^{ce} + \Pi_{Sellers}^{ce} + \Pi_{3rd\ \ Party}^{ce}} \cdot 100 \qquad [9]$$

The denominator in equation [9] is the profits to buyers, sellers, and third-parties using competitive equilibrium prices and quantities. Note that the superscript, *, is replaced by the superscript, *ce*. Efficiency will always be a value between 0 and 100 percent because total surplus in the numerator can never exceed total surplus in the competitive equilibrium. A perfectly competitive market will realize the maximum possible surplus (the competitive equilibrium surplus) and will be 100 percent efficient.

### *Market Efficiency*

In previous network experiments, highly competitive outcomes have been reached when a command and control type constraint is placed on the network (Murphy, 1999; McCabe *et al.*, 1989, 1991, 1993). For example, Murphy (1999) placed a minimum flow constraint on canals in a water network in order to minimize damages to the environment. These experiments reached 99 to 100 percent efficiency within 3 periods and showed very little volatility. In fact, mean efficiency for this treatment equaled 100 percent (the first 2 periods excluded) with a standard deviation of only 1 percent. Since similar network experiments have consistently yielded such highly competitive outcomes, we can attribute less than efficient outcomes in this research to the actual market mechanism. In other words, decreases in efficiency in any one treatment imply that the institution is the likely cause of that decrease. It is important to emphasize, however, that although these market are highly efficient, the competitive equilibrium *level* of total surplus with fixed constraints is lower than those in which these constraints are flexible.

Figure 5 shows the average efficiency in each period for each treatment. Each point on a trend line represents the average efficiency in a given period for all the individual experiments within that treatment. Recall that odd numbered periods are wet years and even numbered periods are dry years. Efficiencies were calculated for each year type (wet or dry) separately but no statistical differences were found so the data are pooled together in this figure. The RevTax treatment produced the most efficient results and also showed the least variation, whereas the 3PBuyer experiments rarely even reached a mean efficiency of 90 percent in any given period. The UnitTax experiments exhibited some volatility but reached average efficiencies of over 90 percent by the later periods.

Table 1 summarizes the mean efficiency for each treatment. Periods 1 through 4 (the first two wet years and the first two dry years) are eliminated from this calculation because during early periods, participants are considered to be learning and becoming accustomed to the software. These early periods are generally very inefficient and are excluded from the analysis.

**Table 1: Mean Market Efficiency for Each Treatment**
Periods 1-4 excluded

| **Treatment** | | |
|---|---|---|
| 3Pbuyer | | |
| | Mean | 83.71 |
| | Std Dev | 7.52 |
| | CE Surplus-Wet | 7414 |
| | CE Surplus-Dry | 7626 |
| UnitTax | | |
| | Mean | 88.74 |
| | Std Dev | 5.68 |
| | CE Surplus-Wet | 4293 [a] |
| | CE Surplus- Dry | 6704 [b] |
| RevTax | | |
| | Mean | 92.08 |
| | Std Dev | 5.49 |
| | CE Surplus-Wet | 4293 [a] |
| | CE Surplus- Dry | 6872 [b] |

[a] Competitive equilibrium surplus in the wet years is based on a 0 per unit (0% revenue) tax rate. Higher tax rates will result in lower possible surplus.

[b] Competitive equilibrium surplus in the dry years is based on a $16 per unit (14% revenue) tax rate. These are the tax rates assuming no carry over from the previous year.

The efficiencies in Table 1 support the results from Figure 5. The RevTax treatment shows the greatest efficiency, UnitTax is slightly less than RevTax and the 3PBuyer experiments have an mean efficiency of only 84%. Although the overall efficiency of the UnitTax is less than the RevTax experiments, we can see from Figure 5, that the volatility of the UnitTax experiments is greater than the RevTax. In the later periods, we see mean efficiency reaching levels similar to the RevTax experiments. In fact, by eliminating periods 1 through 10 instead of just periods 1 through 4 when calculating efficiencies the mean efficiency for the UnitTax experiments rises from 88.74% to 91.09%. The mean efficiency for the RevTax treatment only rises from 92.08% to 93.07%.

The two right hand columns of Table 1 show the total amount of surplus realized by the competitive equilibrium. It is important to note that there is a greater possible amount of surplus in the 3PBuyer experiments than in either of the tax experiments. With the participation of third-parties in the market, the total amount of surplus available increases. Even though efficiency levels are low in the 3PBuyer experiments, the average amount of surplus realized by the participants of the 3PBuyer experiments across wet and dry years is 6288 experimental dollars. This is compared to 4736 and 5084 experimental dollars realized on average by the UnitTax and RevTax experiments respectively. The 3PBuyer experiments have the highest level of total surplus in the competitive equilibrium because third-party effects are fully captured in the market.

In this research, we want to know whether the type of treatment influences market efficiency. Although these efficiencies seem different, are they statistically different from each other? To answer this, the following regression was run:

$$Efficiency = \beta_0 + \beta_1 \cdot Per1to10 + \beta_2 \cdot UnitTax + \beta_3 \cdot RevTax \qquad [10]$$

In this regression, the dependent variable, *Efficiency*, is the efficiency calculated for each period in each individual experiment yielding 202 observations. *Per1to10* is a dummy variable which equals one if the period is less than or equal to 10 and zero if the period is greater than 10. *UnitTax* and *RevTax* are also both dummy variables which identify each of these two treatments. A dummy for 3PBuyer was left out in order to create a benchmark to compare efficiency levels. From this specification, we can interpret the intercept as the average efficiency in the 3PBuyer experiments for all periods greater than 10. The results from this regression are presented in Table 2.

**Table 2: Results from Regression [10]**

| Variable | |
|---|---|
| **Intercept** | |
| Coefficient | 87.330 |
| Std Error | 1.2209 |
| t-value | 71.53 |
| p-value | 0.0 |
| **Per1to10** | |
| Coefficient | -5.879 |
| Std Error | 1.0045 |
| t-value | -5.85 |
| p-value | 0.0 |
| **UnitTax** | |
| Coefficient | 1.787 |
| Std Error | 1.3266 |
| t-value | 1.35 |
| p-value | 0.18 |
| **RevTax** | |
| Coefficient | 7.041 |
| Std Error | 1.3165 |
| t-value | 5.35 |
| p-value | 0.00 |

Both the coefficients for *Per1to10* and *RevTax* are highly significant at the 5% level with p-values of 0.00. Over the first ten periods, we can expect an efficiency decrease of 5.88 percent. This is consistent with the idea that participants learn how to realize greater profits as the experiment progresses. The coefficient on the *RevTax* variable implies that for these experiments, we can expect an efficiency increase of 7.04 percent over the 3PBuyer experiments. Although the coefficient on *UnitTax* is positive implying that the UnitTax treatment increases efficiency as compared to the 3PBuyer experiment, this coefficient is not statistically significant at the 5% level. An F-test was run to test whether the coefficients on *UnitTax* and *RevTax* are equal. The null hypothesis that $\beta_2 = \beta_3$ was rejected with an F-statistic of 21.46 and a p-value of 0.00. This tells us that there is a statistically significant difference between the effect that a Unit Tax has on efficiency and the effect of a Revenue Tax.

In this experimental setting, we saw the greatest decreases in market efficiency in the 3PBuyer experiments. As noted earlier, this does not necessarily imply that this market mechanism is less preferred to either of the tax schemes because the 3PBuyer experiments exhibited higher *levels* of CE surplus. By incorporating the third-parties into the market, total available surplus in the market increased allowing the 3PBuyer experiments to capture greater amounts of surplus than either of the tax experiments despite the low efficiencies in each period. This leads to the question of whether allowing third-parties to actively participate in the market will cause higher total surplus. Ultimately this is an empirical question because we can only make inferences about total surplus levels in regard to this market setting. Results could vary under different demand and supply parameters due to market shares of surplus by individual subjects, and elasticities of demand and supply. Based on the experiment results, we can however make the following conclusions:

- Mean efficiencies in the RevTax treatment were highest and exhibited the lowest amount of variation. The mean efficiency in the UnitTax treatment was slightly less than the RevTax treatment. The UnitTax treatment, however, exhibited a great deal of volatility in early periods but by later periods reached mean efficiencies comparable to the RevTax experiments. The 3PBuyer treatment showed the greatest decreases in efficiency with hardly any periods reaching 90% efficiency.
- Although efficiencies in the 3PBuyer experiments are lower, the total amount of surplus is much higher because third-party effects are entirely captured within the market. Losses in total surplus in the tax systems can be attributed to the fact that the taxes are not levied directly on the externality. They are shared by the market as a whole.
- Variation in efficiencies for the RevTax and 3PBuyer treatments can partly be attributed to experimental effects (i.e., variation due to certain cohorts of participants and not the market mechanism itself). There were no experimental effects within the UnitTax treatment.

### *Equilibrium Prices and Quantities*

Highly efficient markets, such as the minimum flow experiments by Murphy (1999), exhibit prices and quantities that quickly converge on the competitive equilibrium prices and quantities. These are the prices and quantities which exhaust all the gains from trade. In the last section we saw decreases in efficiency for all three treatments (3PBuyer, UnitTax and RevTax) of up to 20 percent with the 3PBuyer experiments showing the lowest average efficiencies and the RevTax experiments with the highest average efficiencies. We now want to look at the prices and quantities associated with these decreases in efficiency and the impact that these have on each treatment. Below is a summary of some key results prices and quantities that we observed in these experiments, Mastrangelo (2001) provide the details:

- For the 3PBuyer experiments, at the buy nodes and reservoirs, observed prices are generally higher than the competitive equilibrium prices but lower than the prices that would occur in competitive equilibrium assuming the third-party acted as a pure free-rider. This trend is independent of whether the year is wet or dry. Quantities, on the other hand, are generally lower than both of the scenarios in the wet years. In the dry years quantities increase above the pure free-riding situation, but still remain below the competitive equilibrium
- Higher prices and lower quantities relative to the competitive equilibrium can be partly attributed to the third-parties tendency to under-reveal their true willingness to pay. Especially at node 3rd Party-1, the prices converged on zero (pure free-rider). The year type did not affect the third-party contribution.
- For both tax treatments (UnitTax and RevTax), at all nodes, prices were higher and quantities lower than under the competitive equilibrium with no market mechanism (i.e., no 3rd party participation, and no tax).
- For the tax treatments, in the wet years, actual prices are consistently higher than the competitive equilibrium prices given specific tax rates, and quantities are lower. More often, however, the RevTax experiments converged on the competitive equilibrium prices and quantities than in the UnitTax experiments.
- Because the tax rate is calculated *a priori,* and the actual outcomes do not equal the competitive equilibrium, the tax rate is imperfect. If the tax were perfect, we would see a tax rate of zero in all wet years, but in the laboratory we consistently witnessed tax rates of up to $10 per unit or 14%. This reflects the inability of the fund to compensate all of the damages in the dry years. We saw less variation in the tax rate in the dry years however, which tells us that these shortcomings were generally made up for in the wet years.
- The non-zero tax rate in the wet years has serious equity issues if the subjects who trade and must pay the tax in the wet years are not the same subjects who trade water in the dry years when all the damages occur. Essentially, part of the burden of the tax is passed on from dry years to wet years.

### *Distribution of Surplus*

When evaluating a market mechanism it is important to look at who gains and who loses in comparison with the competitive equilibrium. How is the distribution of surplus divided between buyers, sellers and third-parties under different treatments? Does the distribution change between the wet years when demand is low and supply high and the dry years when demand is higher and supply lower? For an individual or group of participants, the share of competitive equilibrium surplus is the ratio of the amount of surplus earned by that group of participants during the experiment to the amount that would be earned by that same group in a perfectly competitive market. Unlike market efficiency, this number is not bounded between 0 and 100 percent because it is possible for individual participants to capture a greater share of the surplus than they would receive under competitive equilibrium (but not all groups can exceed 100% since gains by one group must be offset by losses for another). Following are some key results from an analysis of surplus distribution, Mastrangelo (2001) contains the details:

- In all treatment types, buyers capture a larger share of their competitive equilibrium surplus in the wet years as compared to the dry years. Sellers, on the other hand, are better off in the dry years. The extent to which the wet and dry years differ, varies by treatment.
- The tendency of third-parties to free-ride in the 3PBuyer experiments caused decreases in overall buyer welfare and even more drastic reductions in seller welfare. The third-parties, however, have a great incentive to exhibit this free-riding behavior since they were able to realize up to almost 300% of the competitive equilibrium surplus in some cases. Since third-party contribution is the same regardless of the year type, third-parties free-ride to a greater extent in the dry years than in the wet years
- In the tax treatments, it is easier for sellers to shift the tax incidence to the buyers under a per unit tax then a revenue tax. This is exacerbated in the dry years when there is less water available but demand is relatively high.

## Conclusions

In the early 1990's, the drought water banks clearly demonstrated the economic benefits that voluntary short-term water transfers can provide to California. However, the water banks relied upon predetermined "prices" set by the Department of Water Resources, and these fixed "prices" did not adjust with changes in supply or demand. The use of computer-coordinated "smart" markets for water offer California the potential to increase the efficiency of short-term water transfers while protecting environmental, social and economic interests (Murphy, 1999; Murphy *et al.* 2000). This project extends that research by testing whether and how these computer-coordinated water markets can incorporate third-party values into the water allocation mechanism. Some key results are as follows:

- There are two ways in which we can think about market efficiency:
    1. For a given institution, compare the observed total surplus with the competitive equilibrium surplus for that particular institution. Using this definition, if efficiency reaches 100%, then the market has achieved the highest possible level of total surplus *for that institution (or set of market rules).* This does not preclude the possibility that some other institution may generate higher levels of total surplus in the competitive equilibrium.
    2. For a given institution, compare the observed total surplus with the competitive equilibrium surplus for the institution that yields the highest possible level of total surplus. Using this definition, if efficiency reaches 100%, then the market has achieved the highest possible level of total surplus *for any institution (or set of market rules).*

  We make this distinction because some command-and-control institutions impose constraints (*e.g.*, limits on water exports) that limit the potential gains from trade. Although these constrained institutions may be 99 to 100% efficient by the first definition, they are usually less efficient by the second definition. In other words, these command-and-control institutions may perform well *given the constraints*, but there are other, more flexible institutions, that may be able to improve social welfare.

The institutions considered in this research range from: (1) a pure command-and-control mechanism, *i.e.*, fixed limits on the amount of water that may be exported from a region,[4] (2) to a combination regulatory/market mechanism, *i.e.*, per-unit or revenue taxes on transfers, (3) to a pure market solution, *i.e.*, active third-party participation in the market. As the degree of regulation decreases, the maximum potential level of total surplus increases.[5] In practice, however, we want to know whether these potential gains will be realized.

The degree to which the potential gains will be realized is an empirical question that we cannot address using laboratory experiments. However, we can draw the following conclusions from the experimental results:

- o Although some form of third-party participation in the market may be theoretically optimal, it is prone to strategic behavior and free-riding that may erode most, if not all, of the efficiency gains.
- o Fixed constraints on the volume of water that may be exported from a region are likely to be stable and highly efficient using definition 1 above, but these benefits are offset by a reduction in maximum potential gains from more flexible institutions.
- o Taxing transfers to compensate victims as described above may not be a theoretically optimal mechanism, but the market still yields highly efficient and stable outcomes, and is more flexible than fixed limits on water transfers. Although further research is necessary, this mechanism offers a promising balance of efficiency, equity and market stability.

- One important potential disadvantage to the tax mechanisms is the threat of bankruptcy. In a prolonged drought, it is possible that the compensation fund may run a deficit for a number of consecutive years. If there is a deficit in a given year, the tax rate in the following year would increase to make up for the shortfall. However, if there are too many tax increases without an infusion of additional capital, it is conceivable that future tax rates could escalate to a level that effectively makes transfers prohibitively expensive. It is likely that minor modifications of the mechanism we tested could minimize this threat of bankruptcy. One possibility that we did not test would be to spread any revenue shortfalls over multiple years, rather than a single year. This would reduce the magnitude of the year-to-year tax rate adjustments, but would also impose a tax burden on future water traders who may not have been responsible for the damages.

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[4] As discussed in the body of the report, this command-and-control mechanism was not directly tested in this project. However, we expect that the results of Murphy (1999) would be similar and therefore we make inferences about how those results would be applicable here.

[5] This follows from a fundamental result in any optimization problem: as binding constraints are relaxed, all else equal, the value of the objective function (in our case total surplus) will increase or remain unchanged.

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# Appendix A. Some Background on Experimental Economics and 'Smart' Markets

Vernon Smith, among others, began using laboratory experiments to study market behavior and performance about fifty years ago. Over that time, the use of laboratory experimental methods in economics has evolved into a major field of research within microeconomics (Smith, 1991). The advantage of studying experimental markets, rather than direct observation of field institutions, is that the researcher can observe human behavior in a simplified, controlled environment, and he can modify the institution in various ways to test specific hypotheses (Friedman, 1993). According to Smith (1982), "control over preferences is the most significant element distinguishing laboratory experiments from other methods of economic inquiry" (p. 931).

Researchers have performed numerous experiments to test different aspects of economic theory, including institutions and market performance, auctions and institutional design, and industrial organization. Recently, they have begun to explore the efficiency, speed of convergence, price stability and dynamic characteristics of proposed new institutions, particularly those in network industries which involve complex allocation problems, such as markets for electric power and natural gas (McCabe, et al., 1989, 1990a, 1990b, 1991).[6] Because California's water supply infrastructure can also be viewed as a network, similar to natural gas or electric power, we can adapt the so-called 'smart' market concept to water transfers in the state.

How do the economics experiments work in general? They use reward-motivated subjects, usually students, to represent the various economic agents. These subjects are given either a willingness-to-pay (WTP) demand function, or willingness-to-accept (WTA) supply function, depending upon the role they will be playing. These supply and demand schedules are usually step-functions. Each subject knows the rules of the experiment (*i.e.*, the institution), as well as their own valuation of the goods on the market (*i.e.*, their supply, or demand, step-function). The subjects are given no information about the value functions of the other agents. Agents attempt to maximize their profits, which are defined as the difference between the equilibrium price and their respective WTP or WTA, by submitting bids (or offers) in a computer-assisted auction. Because the students keep all the profits that they earn during the experiment, they are given an incentive to act as profit-maximizing economic agents. Due to fatigue, experiments are usually less than two hours, and payouts typically range between six and sixty dollars (McCabe, et al., 1989).

The 'smart' markets in these experiments are structured as a computer-assisted uniform price sealed-bid double auction. It is probably worth decomposing what this means. In general, a double auction is one in which buyers submit bids and sellers tender offers for a particular good. A binding contract occurs when a buyer (seller) accepts a standing offer (bid) of any seller (buyer). In the 'smart' market variation of the double

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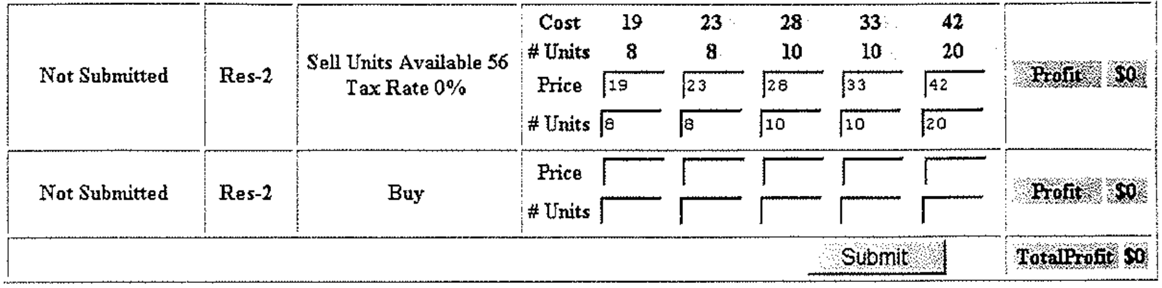
[6] A networked industry can be viewed as one in which buyers and sellers are connected by a transport pipeline; in the case of water markets, this 'pipeline' would include the rivers and canals. Of course, transporting water throughout the state is not costless, and there are various types of capacity and usage constraints on the water delivery network in California. Thus, buyers actually demand a composite, or bundled, good: *delivered* water. On the supply side of the market, there are two types of agents: sellers of water, and providers of water transportation (such as the SWP or CVP).

auction, buyers (sellers) simultaneously submit bids (offers) to a central computer which then determines equilibrium prices and quantities which maximizes total welfare based on the submitted bids and offers. Once all of the bids and offers have been submitted, the market is closed and the central computer determines the water allocation by maximizing total surplus as defined by the submitted bids and offers. By requiring agents to submit their bids and offers to a central computer, the 'smart' market is able to combine the information and incentive advantages of decentralized ownership rights with the coordination advantages of central processing. By doing so, these experiments allow researchers to "elicit the required information in complicated problems that are not well understood theoretically" (McCabe, et al., 1991, p. 534).

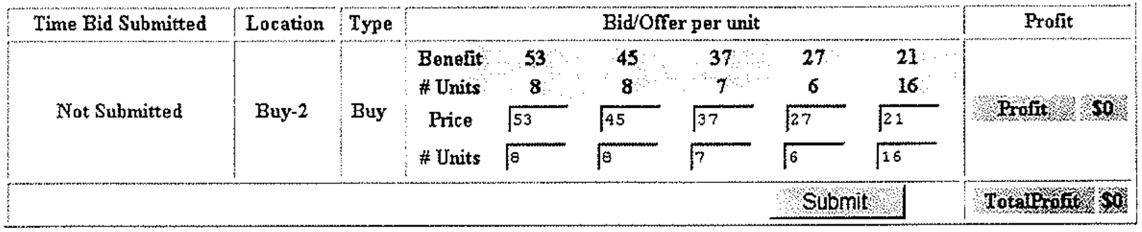
If all agents reveal their true WTP or WTA, this would result in the competitive market equilibrium (which maximizes total surplus). Experimental market efficiency can then be measured by comparing total surplus achieved in the experimental setting with the maximum possible surplus defined by the competitive equilibrium. In addition, the experimental market will provide insights into price discovery, the rate of convergence to the equilibrium, price stability, and the consistency with which the equilibrium is attained.

Figure 1: Example of a Seller Bidbook



| Time Bid Submitted | Location | Type | Bid/Offer per unit | | | | | | Profit |
|---|---|---|---|---|---|---|---|---|---|
| Not Submitted | Res-2 | Sell Units Available 56<br>Tax Rate 0% | Cost | 19 | 23 | 28 | 33 | 42 | Profit $0 |
| | | | # Units | 8 | 8 | 10 | 10 | 20 | |
| | | | Price | 19 | 23 | 28 | 33 | 42 | |
| | | | # Units | 8 | 8 | 10 | 10 | 20 | |
| Not Submitted | Res-2 | Buy | Price | | | | | | Profit $0 |
| | | | # Units | | | | | | |
| | | | | | | | | Submit | TotalProfit $0 |

Figure 2: Example of a Buyer Bidbook



| Time Bid Submitted | Location | Type | Bid/Offer per unit | | | | | | Profit |
|---|---|---|---|---|---|---|---|---|---|
| Not Submitted | Buy-2 | Buy | Benefit | 53 | 45 | 37 | 27 | 21 | Profit $0 |
| | | | # Units | 8 | 8 | 7 | 6 | 16 | |
| | | | Price | 53 | 45 | 37 | 27 | 21 | |
| | | | # Units | 8 | 8 | 7 | 6 | 16 | |
| | | | | | | | | Submit | TotalProfit $0 |

Figure 3: Southern California Water Network

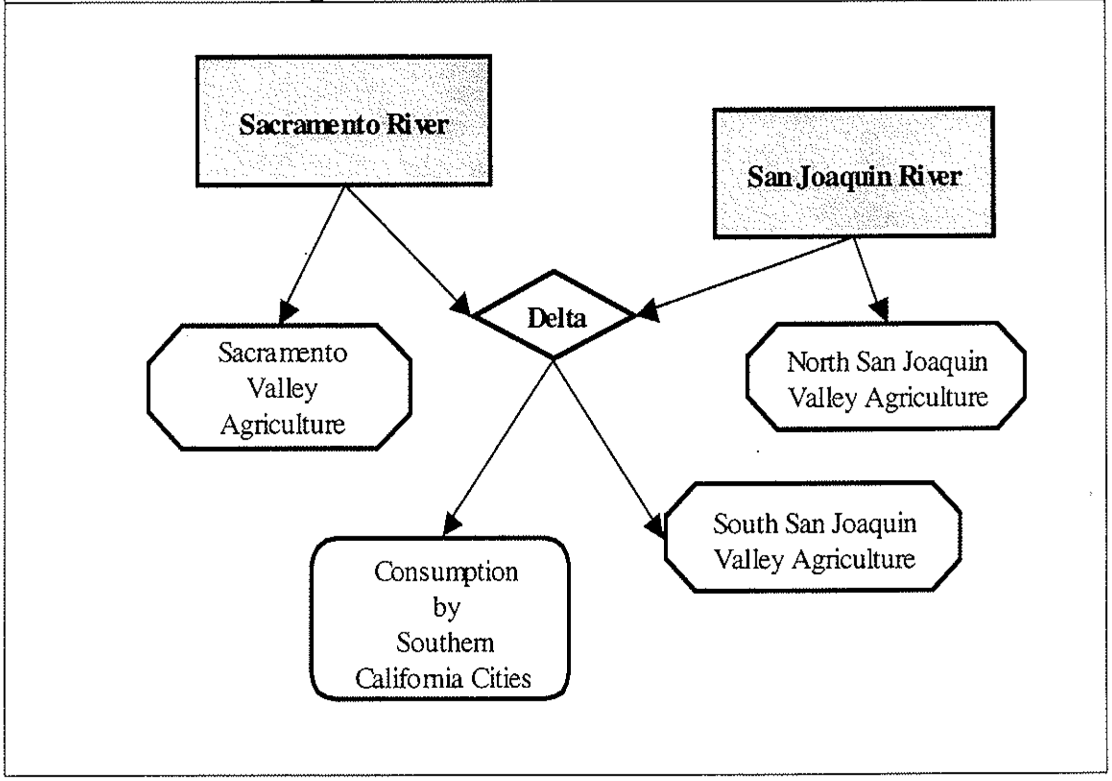


Figure 4: The Experimental Water Market

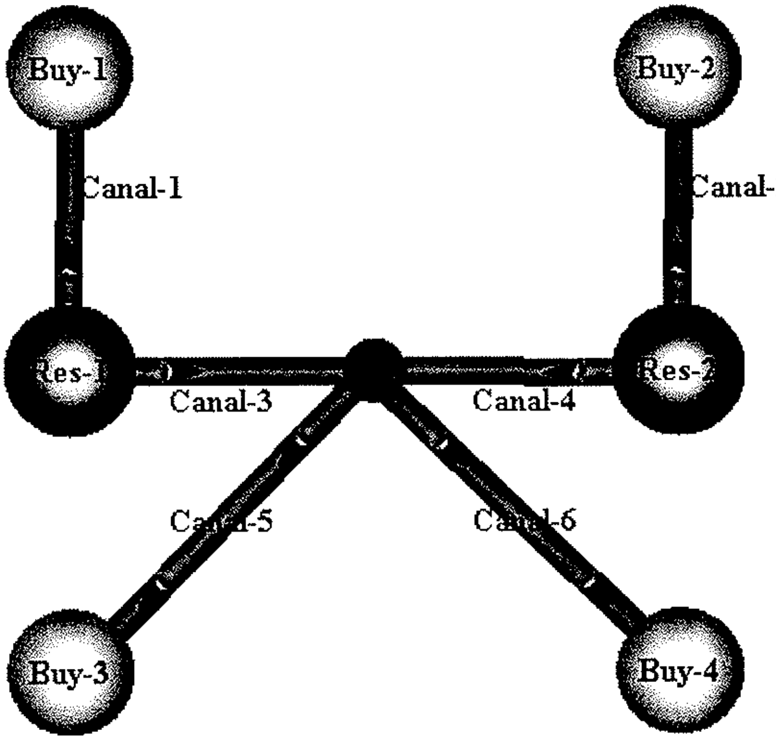


Figure 5: Average Efficiency by Treatment Type in Each Period