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Mechanisms for Addressing Third Party Impacts Resulting From Voluntary Water Transfers

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Keywords: arbitration, experiments, third party impacts, environmental impacts, water markets

JEL Classification: Q25, C9, H41, Q28

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Running title: Water markets and third party impacts

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Abstract

This paper 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 market in which third parties actively participate. The results indicate that there are some important trade-offs in selecting a policy option. 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. Taxing transfers and compensating third parties offers a promising balance of efficiency, equity and market stability.

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1. Introduction

Despite the comparatively short experience of the western US states 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 [3]. However, until it can be demonstrated that a water market institution is capable of protecting environmental and third party values, voluntary water transfers will not realize their full potential as an integral part of a water management strategy in the 21st century. Hanak [7] examines the rise of local governmental resistance to water markets in California. Currently, 22 of the state's 58 counties have passed local county ordinances preventing or restricting the export of water. Seventy three percent of these ordinances were passed since 1996. Water markets in the western US are now at a stage where third party compensation rules that are perceived to be equitable and efficient are required to move the adoption of water markets beyond the current level.

This paper uses laboratory experiments to test alternative water market institutions designed to incorporate the value of non-consumptive water into the allocation process.¹ We focus on third parties, specifically rural communities that depend upon irrigated agriculture but are not party to the market transaction, however the results apply to most non-consumptive uses including environmental impacts and instream flow values. Water is frequently made available for transfer by fallowing land. The effects of reduced crop production can be widespread in the local economy due to changes in the sales of farm inputs. For example, McClurg [16] reports that the water transfers out of Yolo County, California after the 1991 Drought Water Bank resulted in 450 lost jobs. More recently, an agreement between the Metropolitan Water District of Southern California and the Palo Verde Irrigation District includes a \$6 million payment to the community to offset economic harm from land fallowing [19]. Although these third party

impacts may be pecuniary externalities and the result of a well-functioning market, for a proposed new exchange mechanism to be viable it cannot ignore these effects.

Successful implementation of an institution that can facilitate long-distance water transfers requires a substantial amount of coordination to achieve an efficient water allocation, especially in the presence of interdependent uses, such as third party impacts or instream flows [1, 6, 8, 10]. Most water rights are defined in terms of consumptive use, and non-consumptive rights are often protected by constraints on water transfers such as minimum instream flow requirements, taxes on transfers, restrictions on the quantity of water that may be exported from a region, or “no injury” rules. When these constraints on transfers are binding, the resulting allocation will be inefficient [20]. Both Huffman [8] and Griffin and Hsu [6] suggest that the creation of property rights for non-consumptive use may lead to more efficient allocations. Since the externalities associated with water transfers vary by location, efficiency will usually require location-specific pricing [6, 20]. However, a water market with spatially discriminative prices is likely to be complex and face high transaction costs associated with finding trading partners. Thus, institutional design plays an important role in the transmission of information and the evolution of prices such that the water market yields efficient allocations [20].

With the advent of high-speed communication networks and low-cost computing resources, the landscape of exchange system architectures has changed dramatically over the past decade. The recent development of ‘smart,’ computer-coordinated markets provides the promise of developing decentralized solutions to such complex resource allocation problems. McCabe *et al.* [11, 12, 13, 14, 15], have demonstrated the ability of these ‘smart’ markets to achieve efficient allocations in the natural gas and electricity industries. Dinar *et al.* [4] and Murphy *et al.* [18], subsequently apply the ‘smart’ market concept to spot water markets with similar

success. These markets allow decentralized agents, who best know their own circumstances, to submit virtually unlimited messages (bids to buy, offers to sell, logical and budgetary constraints) to a computer dispatch center. The center can then compute prices and allocations by applying a set of rules, often a sophisticated optimization algorithm that maximizes the possible gains from exchange, while observing constraints. By doing so, these markets can lower transaction costs, facilitate trades that may not have otherwise been effected, and increase overall market efficiency. The ability of these electronic markets to address complex allocation problems is a particularly attractive feature for water markets, especially in the presence of environmental and third party impacts.

It is critical that any water market mechanism not only be efficient and stable, but also acceptable to all parties involved. This means a viable water market institution must incorporate the third party impacts into the allocation mechanism. Hence, this paper uses laboratory experiments to test three different ‘smart,’ computer-assisted water market institutions that are designed to account for third party impacts in the allocation process. The institutions tested are primarily based on policy options that have been proposed by government agencies and academics.

One of the options provides no regulatory protection of third parties but allows these individuals to actively participate in the water allocation process by bidding for water to supplement existing flows to the region. The remaining two options, based on the California Model Water Transfer Act [5], explore different tax schemes which decouple the water allocation process from victim compensation. The basic process is simple: A regulator sets the tax rate at the beginning of the water year and trading occurs with participants paying the tax on all water transfers. Tax revenue goes directly into a fund which is managed by a neutral

arbitrator. At the end of the water year, victims of a water transfer may file a claim requesting compensation from the fund and the arbitrator renders a binding final decision to each claimant. Any surplus or deficit in the fund after compensation is carried over to the next water year.

This paper describes a series of laboratory experiments designed to test these alternative institutions. The key results are: (1) although third party participation in the market has the advantage of allowing those affected by the transfers to express their willingness-to-trade, it is prone to strategic behavior and free riding that may erode the efficiency gains; and (2) taxing transfers to compensate victims as described above may not be able to maximize total social welfare, 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, a tax on water transfers is a promising means of promoting highly efficient allocations while ensuring that third parties are fully compensated.

2. Experimental Design

In this paper, we use a controlled, laboratory setting to test three different water market institutions designed to account for third party impacts. The first institution facilitates direct third party participation in the allocation process, the last two institutions tested in this paper incorporate taxes on water transfers to compensate victims. 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 economic activity and higher levels of employment. Similarly, exporting water out of a region generates third party damages. During droughts, rapid approval of short-term transfers is critical and there may not be adequate time for a lengthy transfer review process to quantify third party damages. Thus, we assume that although third parties know the

expected level of damages with certainty, government regulators do not have this information until after the transfers have been completed and the damages have been realized.

2.1. Alternative 1: Third parties participate in the water market (3PBuyer)

The first alternative, denoted *3PBuyer*, tests a market structure that allows third parties to actively participate in the water allocation process. This mechanism is similar to the design by Murphy [17], in which an Instream Flow District was created to represent instream flow values in the market. In this institution, the third parties do not have property rights to the water, but can participate in the market by subsidizing consumptive demands in their region. By contributing to the provision of the water, they have the ability to increase the flow into their region thereby lowering third party impacts. Since third parties best know their own circumstances and willingness to trade, the perfectly competitive equilibrium would yield efficient outcomes, assuming clearly defined property rights and no strategic behavior.²

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 its 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 [17] suggest that free riding in this type of market structure does exist, and tends to reduce market efficiency and introduce volatility into the market.

2.2. Alternatives 2 and 3: Water transfer taxes and third party compensation

The California Model Water Transfer Act [5] provides the basis for the two taxing mechanisms. Under the proposed Act, all short-term water transfers are allowed to occur, but water transfers are taxed and the revenue goes into a fund from which affected third parties can be compensated. At the end of the water year, anyone damaged by a water transfer may file a claim for compensation. An impartial arbitrator evaluates any claims and uses the tax revenue to compensate victims. Because the water transfer is decoupled from third party compensation, this type of institution requires two components: (1) a taxing mechanism to generate revenue to compensate third parties, and (2) an arbitration mechanism through which victims can file claims for damages.

Taxing mechanism. In the two tax treatments examined, either a per-unit or a revenue tax is imposed on all transfers, and the revenue placed in third party compensation fund. At the end of the water year, an arbitrator evaluates any third party claims and fully compensates them for any damages. For such a compensation mechanism to be viable, it needs to guarantee that (a) third parties are fully compensated, (b) water traders are not paying taxes in excess of damages, and (c) the fund will remain solvent over time. This is equivalent to ensuring that each year total tax revenue equals total damages. The tax rate is set at the beginning of the water year by a regulator who has perfect information on all market participants. With this information, the regulator can estimate the damages that would occur in a competitive equilibrium. What he cannot predict, however, is how participants will actually trade. With perfect foresight, the regulator would set the tax rate such that revenues collected from water transfers would exactly equal the level of third party damages. The fund balance at the end of each year would then be zero.³ In reality, because *estimated* 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. 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 subsequent year.

We consider two types of taxes: a per-unit tax (*UnitTax*) and a revenue or *ad valorem* tax (*RevTax*). Tax revenue from a per-unit tax is based on the total volume of water traded, whereas tax revenue from a revenue tax is based on the total value of the water traded. In our experiments, the water seller is responsible for collecting the tax.⁴ Because the tax rate is imperfect (due to the difference between the actual and competitive equilibrium outcomes), there may be a fund balance from the previous year. This balance may be positive or negative and will affect the tax rate in the next period. The per-unit tax rate for a given water year is determined as:

$$\text{Per Unit Tax Rate} = \frac{\text{Predicted Damages} - \text{Fund Balance}}{\text{Predicted Quantity of Water}} \quad (1)$$

where Predicted Damages are the level of third party damages that would occur in the coming water year in the perfectly 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. The revenue tax is calculated similar to the per-unit tax except that the denominator in equation (1) is replaced with Predicted Revenue, which is the total revenue collected by all sellers in the perfectly competitive equilibrium.

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. Arbitration has become one of the more popular methods of dispute resolution outside the public court system. In typical arbitration systems, the negotiators on both sides 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.

In a “smart market,” such as the one used in this research, traditional two-sided 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” generates the externality. Therefore, we cannot utilize traditional arbitration schemes and have assumed 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.

Clearly, in such an arbitration mechanism there are strong incentives for third parties to over-estimate damages and file frivolous claims. It is incumbent upon the arbitrator to determine the true damages. In this research, we avoid this incentive problem by assuming a perfectly informed neutral arbitrator. This computerized robot arbitrator has perfect information on the value of water for all market participants, including third parties. Using this information, 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 award exact compensation to third parties. 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.

2.3. *A comment on the efficiency of the tax mechanisms*

We should note that such a tax-and-compensation mechanism will not generally produce efficient allocations, essentially because those trades that generate the third party impacts may not be facing 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. Even in a world with perfect information the tax rate would not be efficient because: (1) there is an additional revenue-neutrality constraint which requires the tax rate to be set such that *total* (not marginal) damages and *total* revenues are equal to ensure victims are fully compensated, and (2) allocations are determined simultaneously in a computer-assisted market and it is impossible to identify which trade “caused” the damages. Rather, the damages are caused by the system as a whole. Efficiency would require location-specific tax rates (and subsidies) based on marginal benefits and costs. Although the mechanism is not designed to yield the maximum possible total surplus, it is a practical and viable means of balancing the need to rapidly facilitate water transfers while protecting third parties, particularly when the external effects are unknown at the time of transfer. Lastly, Baumol and Oates [2] point out that there could be additional incentive problems with compensating victims.

2.4. *Experimental procedures*

This research focuses on three different market institutions described in the previous section. These are: (1) third parties as Buyers in the water market (*3PBuyer*); (2) a per-unit tax imposed on all water trades (*UnitTax*); (3) a revenue tax imposed on all water trades (*RevTax*). We present the results collected from eighteen computer-based experiments. Participants for the

experiments were recruited from the university's student population. The experiments utilized web-based water market software designed specifically for this research. Participants 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 trading. 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 were collected. Participants were paid at the end of the second day and averaged \$50 for the two days. This includes a \$20 payment for showing up on time both days plus earnings during the experiments.

The software used for the experiments displayed the entire water network to each participant on his or her computer screen and showed information about the network. The network consisted 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 was assigned specific locations at which he or she was active, and was given an induced demand or supply schedule at each of these nodes. These schedules consisted of five price and quantity steps and only the experimenter, the participant, and the computerized arbitrator and regulator knew these values for water.⁵

All sellers received an inflow of water each period which represents water from rain or melting snow. The supply schedule they saw represented their costs for selling water. The costs were the lowest price for which the sellers could profitably sell their water. Sellers earned money by selling their water at a price above the costs. Profit was calculated by the price they receive in the market multiplied by the quantity sold less any costs.

Buyers submitted bids in each round based on an induced demand schedule. The values they saw were also price and quantity steps which represented the benefit they received from

using the water. Their bids therefore represented the most they are willing to pay for a given amount of water delivered to their location. Buyers' bids included any conveyance costs on the canals plus any taxes. Buyers earned money by purchasing water at a price lower than the benefit they received from consumption. Profit for them was calculated by the dollar benefit received from the water minus the amount they paid for that quantity. Non-consumptive users in the *3PBuyer* experiments also submitted bids based on an induced demand schedule. However, the third parties did not consume the water and received a benefit from the water consumed by others in the region regardless of whether the third party contributed to the provision or not.

Each experiment consisted of 16 to 20 periods in which odd numbered periods were considered 'wet' water years (higher inflows and lower buyer values) and even numbered periods were considered 'dry' water years (reduced inflows and higher buyer values). All wet years were identical and all dry years were identical. Each year, trading occurred in a spot market. Water could not be stored for future use. During the period, participants could submit location-specific bids to buy water and asks to sell water. Each period lasted about 5 minutes and all participants were allowed to submit bids and asks as often as they would like. The last submission before the period ends was the only one the computer uses. When each trading period ended, the central computer took the input data from all participants and solved the following network flow problem:

$$\text{Maximize total surplus:} \quad -\sum_i c_i f_i + \sum_i b_i f_i \quad (2)$$

subject to:

$$\text{balance of flow:} \quad \sum_{i \in S_k} f_k = \sum_{i \in E_j} f_j \quad (\forall \text{ nodes } j); \quad (3)$$

conveyance capacity:
$$d_i \leq f_i \leq u_i \quad (\forall \text{ arcs } i) \tag{4}$$

Each arc (i) in this formulation represents one bid or offer. If a buyer makes a multi-part bid, then each part is represented by separate, parallel arcs. Multi-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 treated as negative costs) and b_i is the third party 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 (3) maintains the balance of flow at each node j . Intuitively, equation (3) describes the network and defines the set of feasible trades. Constraint set (4) ensures that the flow on each conveyance arc does not exceed the stated lower or upper bounds. In the tax treatments, third parties are not active, so $b_i = 0$, and the seller's bid includes both the seller's asking price and the tax.

Solving the linear programming problem above yields not only the optimal flows (and production and consumption patterns), but also the set of location-specific shadow prices, λ_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. The software displays the results immediately following each period including profits and which bids or asks were accepted.

The laboratory water market was a simplified version of the California water network. Figure 1 contains an illustration of the laboratory water market. There were two main surface water sources: the Sacramento and San Joaquin Rivers. These flow into the Delta from which

water flows to Southern California cities through the Central Valley Project and the State Water Project. In addition to consumption by Southern California cities, there were three agricultural centers that use the water: Sacramento Valley Agriculture, North San Joaquin Valley Agriculture, and South San Joaquin Valley Agriculture.

<<INSERT FIGURE 1>>

The market was a sealed-bid uniform-price double-auction and consists of 16 roles. Each subject in the experiment may have played more than one role. The two upper consumption nodes, Buy-1 and Buy-2, each had three buyers active. Consumption nodes Buy-3 and Buy-4 each had a single buyer. There were three water sellers located at each of the two reservoirs. In addition to the water being traded between the buyers and sellers, third party impacts occurred at the two regions represented by nodes Buy-1 and Buy-2. There was one participant at each of these nodes who had non-consumptive demand for water in that region. Third party damages were dependent on the amount of water consumed in the region (damages increase as consumption decreases).

3. Results

There are three measures of market performance that we discuss in this section: efficiency, price stability, and distribution of surplus. After defining the terms, we use these criteria to evaluate the performance of the water market. 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 for delivered water, P_j^* , and each buyer b earns a profit of:

$$\Pi_{bj}^* = B_{bj}(Q_{bj}^*) - P_j^* Q_{bj}^*, \quad (5)$$

where Q_{bj}^* is the equilibrium quantity of water delivered to buyer b at node j . 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:

$$\Pi_{sj}^* = P_j^* Q_{sj}^* - C_{sj}(Q_{sj}^*). \quad (6)$$

Similarly, each third party, p , located at node j , has a benefit schedule that is a function of the aggregate consumption in the region $B_{pj}\left(\sum_b Q_{bj}\right)$. In the *3PBuyer* sessions, the third party may contribute to the provision of water at his location (but will receive benefits from aggregate consumption at his node regardless of third party contributions). In equilibrium, each third party's contribution, or subsidy, to the provision of water at his location is S_j^* , and each third party p at node j earns a profit of:

$$\Pi_{pj}^* = B_{pj}\left(\sum_j Q_{bj}^*\right) - S_j^* \sum_j Q_{bj}^*. \quad (7)$$

Conveyance along each arc was provided at a constant marginal cost. The price for the water itself is uniform throughout the network, and any location-specific differences in the price for *delivered* water reflect conveyance costs and third party contributions. Aggregate earnings for all buyers, Π_{Buy}^* , are the sum of the individual buyers' earnings:

$$\Pi_{Buy}^* = \sum_b \sum_j \Pi_{bj}^*. \quad (8)$$

Aggregate seller earnings, Π_{Sell}^* , and aggregate third party earnings, Π_{3P}^* , are defined similarly.

Note that the computer calculates the realized equilibrium values, denoted by the asterisk superscript, based on the *submitted* bids and asks of each agent. Using the true supply and demand schedules, we can also calculate the competitive equilibrium prices, allocations, and earnings for each subject. The competitive equilibrium values will be denoted by replacing the asterisk 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:

$$Efficiency = \frac{\Pi_{Buy}^* + \Pi_{Sell}^* + \Pi_{3P}^*}{\Pi_{Buy}^{ce} + \Pi_{Sell}^{ce} + \Pi_{3P}^{ce}} \cdot 100 \in [0, 100\%]. \quad (9)$$

The competitive equilibrium results in an allocation that maximizes the total possible surplus for a given institution and environment, thus, a perfectly competitive market will be 100 percent efficient.

Result 1. *The revenue tax treatment clearly produced the most efficient outcomes. The evidence is mixed about whether active third party participation and a unit tax yield comparable levels of efficiency.*

The tax rate in each period of an experiment is likely to vary to account for any non-zero balances in the compensation fund (equation 1). Therefore, we adjust the definition of competitive equilibrium surplus to reflect the total surplus that would occur in a competitive market given the actual tax rate for that period. Table 1 presents the mean and median efficiency for each of the three treatments. We present the summary statistics for all periods (excluding

periods 1 and 2),⁶ and again after dropping periods 1 through 10 to get a sense for how these markets converge in the later rounds as participants gain experience. By all measures, the *RevTax* treatment consistently yielded the highest efficiency. Mean and median efficiency in all periods (92% and 93%, respectively) was greater than either of the other two treatments. Moreover, the efficiency in 71% of the *RevTax* periods exceeded 90%, whereas less than one-third of the periods in *3Buyer* and about 40% of the periods in *UnitTax* exceeded this benchmark. For all three treatments, performance increased in the later rounds.

<<INSERT TABLE 1>>

One of the *UnitTax* experiments, *UnitTax05*, appears to be an aberration, with mean efficiency only 72%, compared to 88% for the other five *UnitTax* experiments. This group started slow: the average efficiency in the first five periods (not including periods 1-2) was 61%, but in the last five periods efficiency increased substantially to 83%. In Table 1, we present descriptive statistics with and without this experiment.

The *3PBuyer* treatment has the lowest median efficiency in all periods, as well as just the later rounds. *3PBuyer* also has the lowest mean efficiency in the later rounds and the lowest share of periods with efficiency above 90%. We used both Wilcoxon rank sum and median two-sample tests to determine whether these differences in efficiency across treatments were statistically significant. The results of these pairwise comparisons strongly reject (p-value <.0001) the null hypothesis that the efficiency in the *RevTax* equals that of either *UnitTax* or *3PBuyer*. However, the comparison of efficiency for *UnitTax* vs. *3PBuyer* are mixed. When *UnitTax05* is included, there is no statistically significant difference (at 5% level) in efficiency using all periods, however in the later rounds this difference does become significant. If *UnitTax05* is excluded, the null hypothesis of equal efficiency is strongly rejected.

In addition to the non-parametric tests, we also used a mixed effects model to estimate efficiency while controlling for group effects. Table 2 reports the results of a mixed effects model in which efficiency is a function of treatment, type of water year (wet or dry), a dummy variable for periods 3-10. The 18 individual sessions are the random effects. The omitted dummy variables are for *UnitTax* and wet years. After controlling for individual group effects, *RevTax* has a 6.87 percentage point higher efficiency than the *UnitTax* treatment. The coefficient for *3PBuyer* is not statistically significant, suggesting that there is no difference in efficiency between the *UnitTax* and *3PBuyer* treatments. The coefficient on the dummy variable for Periods 3 to 10 is negative and significant, indicating that efficiency increases roughly 5 percentage points in the later rounds of an experiment.⁷ There is no difference in efficiency between wet and dry years.

<<INSERT TABLE 2>>

Result 2. *Although 3PBuyer has lower average market efficiency than RevTax, it has the highest level of realized surplus.*

The second column of Table 3 shows that the competitive equilibrium surplus in *3PBuyer* treatment (7626) is greater than the competitive equilibrium surplus of the two tax treatments (6704 for *UnitTax* and 6872 for *RevTax*).^{8, 9} As previously discussed, the tax rates in the *UnitTax* and *RevTax* treatments are not, and cannot be, efficient because the tax rates are set to equate total expected damages and total expected revenue, and the tax rates are not spatially discriminative.¹⁰ Since the *3PBuyer* treatment fully accounts for the marginal costs and benefits of third party impacts, but the tax treatments do not, the level of total surplus in the perfectly competitive equilibrium for *3PBuyer* is necessarily greater than that in the tax treatments.

<<INSERT TABLE 3>>

With our parameters, the efficiency loss in the tax treatments is around 10%. This 10% efficiency loss has important implications in evaluating the relative merits of each institution. As one can see from Table 3, the average level of realized surplus in the *3PBuyer* treatment was greater than that of either tax treatment (6603, as compared to 6261 and 5788 for *RevTax* and *UnitTax*, respectively). Essentially, *3PBuyer* offers a smaller piece of a bigger pie. What can we say about the relative merits of the different institutions if *3PBuyer* has the lowest efficiency, but the highest level of available surplus? In general, we would expect that *3PBuyer* will always have the highest level of potential surplus, but will be less efficient at extracting this surplus (from Result 1). However, the relationship of the levels of realized surplus from trading in the three institutions is an empirical question that will depend on the magnitude of the efficiency losses due to the tax.

Result 3. *In the two tax treatments, observed prices are slightly higher than the competitive equilibrium, but prices adjust well to changes in market conditions and price volatility is low.*

In addition to market efficiency, we are also interested in how the observed market price compares with the competitive equilibrium price. This evaluation has three dimensions: (1) Does the average market price equal the competitive equilibrium price? (2) Is the observed market price stable with low volatility? (3) Does the observed market price react quickly to changing circumstances? In the two tax treatments, the observed market price performs reasonable well on all three counts.

In this analysis, we use the price at node Buy-1 as the “base” price of water. In all three institutions, the price of the water itself is uniform across all locations in the network. Any

differences in prices at a location are due to conveyance costs and, in the *3PBuyer* sessions, to third party contributions. Table 4 reports the competitive equilibrium and market prices of water for all treatments in both wet and dry years. For the two tax treatments, the mean price is slightly higher than the competitive equilibrium, and, although the difference is generally small, it is statistically significant.¹¹ Because of this, the actual distribution of surplus tends to favor the sellers. That is, sellers garner a larger share of the realized total surplus than they would in a perfectly competitive equilibrium.

Moreover, the market price tracks the competitive equilibrium in both wet and dry years, indicating that the market is responding well to changes in market conditions. The mean price in the *RevTax* treatment was the closest to the competitive equilibrium, which is consistent with the higher levels of efficiency observed in this institution.

<<INSERT TABLE 4>>

As a measure of price volatility within an experiment, we use the mean absolute deviation (MAD) of prices, measured in percent deviations from the mean price for each group (we use the mean for each group, rather than treatment, to control for group effects). All three treatments exhibited low volatility. *RevTax* had the most stable prices, with a MAD of 1.4%. This indicates that, on average, the difference in prices over time for a particular group in the *RevTax* treatment was quite small. The MAD for *UnitTax* was 2.2%, and *3PBuyer* was 3.3%.

Result 4. *In the 3PBuyer treatment, third party contributions are consistent with free riding behavior.*

In the competitive equilibrium, third parties active at nodes Buy-1 and Buy-2 contribute money to increase water consumption in their region. However, given that these third parties receive a

benefit for all water flowing into their region (see equation 7) regardless of contributions, there is clearly a strong incentive to free ride and contribute nothing. Table 5 provides summary statistics for the ratio of actual third party contributions to competitive equilibrium contributions. On average, the third party contribution at Buy-1 is 45% of the competitive equilibrium price, and 69% at Buy-2. With the exception of Buy-2 in wet years, contributions are clearly below the competitive equilibrium, however there is substantial variation in the extent of the free riding across groups. Table 6 presents the results of a mixed effects model using the percent of the competitive equilibrium third party contribution as the dependent variable. The omitted dummy variables are node Buy-2 and Wet Years. There is a significant difference in contributions between nodes and between water year types. Consistent with results in typical public goods experiments, contributions decline by 12 percentage points in the later rounds. With this model, there are substantial group effects. For example, the coefficient for session *3PBuyer01* is -31.5 and is significant at the 1% level. On the other hand, the coefficient for session *3PBuyer06* is 33.4 and is also highly significant. This suggests that, although some free riding was consistently observed, the magnitude of the free riding depends upon the individual. On average, third parties earned more than double what they would in the competitive equilibrium, but there was significant variation across individuals (mean 216%, standard deviation 131%, median 165%). This free riding resulted in about a 25% reduction in the total quantity of water traded, and a transfer of surplus from the communities with the third parties to those without third party impacts. Given that economic activity is dependent on the quantity of water flowing into the region, agricultural communities could face serious long-term consequences if free riding remains a concern.

<<INSERT TABLE 5>>, <<INSERT TABLE 6>>

Result 5. *The tax schemes could have equity implications if traders are not the same from year to year.*

As stated earlier, 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% revenue. The dry year tax rates exhibit less volatility than the wet years due to the fact that most of the negative fund balance is recovered in the wet years when no damages occur. The dry year tax rates tended to converge at or near the perfectly competitive tax rate. Any deficits were generally made up for in the wet years.

Although these results suggest that the mechanism is successful in its intent to compensate third parties, the results also point to important equity implications. Because no damages occur in the wet years, a non-zero tax rate in these years means that traders who participate are paying for damages that occurred in previous years. Essentially, part of the burden of the tax is passed on from dry years to wet years.

An additional point on equity takes into consideration the dry year tax rate as compared to the competitive equilibrium. As mentioned earlier, in the RevTax experiments in the dry years, often there was a positive fund balance *after* compensation. In this case, traders are again paying more than the damages that actually occurred in that period.

One last comment on the tax rates regards the threat of bankruptcy. This market environment was designed so that dry years (when damages are high) alternate with wet years. We found that increasing the tax in the wet years was often sufficient to make up for any shortcomings in the dry years. In the real world, however, a prolonged drought could keep the fund balance in a deficit for a number of consecutive years. Because a deficit causes the tax rate

to increase in the following year, the tax rate could potentially rise to a point where it makes the water transfers prohibitively expensive. One possible means of reducing the likelihood of this occurring is to spread the surplus deficit across multiple years. We recommend this as a possibility for more research before any tax system is implemented.

4. Conclusion

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 California 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. This paper extends that research by testing whether and how these computer-coordinated water markets can incorporate third party values into the water allocation mechanism.

This research used laboratory experiments and a computer-coordinated market to analyze three alternatives designed to protect third parties. These are all based on policy options proposed by government agencies and academics to address this issue. The options tested range from (1) a free-market environment in which third parties are allowed to directly participate in the market and bid for water; (2) a combination regulation and market mechanism which allows all transfers to occur but places a per unit tax on the system in order to create a fund from which third parties are compensated post-market; and (3) a similar mechanism to the previous one, but a revenue tax is used to collect funds.

The RevTax experiments produced the most efficient results using this definition with an average efficiency in each period (excluding periods one through four) of 92 percent. The UnitTax experiments exhibited some volatility in early periods but by later periods reached average efficiencies of over 90 percent. The 3PBuyer experiments, on the other hand, rarely reached average efficiencies of 90 percent in any given period. Further analysis showed that the losses in the 3PBuyer treatment can partly be attributed to free riding by the third parties.

An important aspect to realize is that the lower efficiencies described here do not alone imply that any market mechanism is more or less preferred than another. As pointed out in Result 2, this is because the level of potential surplus varies across institutions. Taking this difference of available surplus into consideration, efficiency can be thought of in a second way: compare average realized surplus with competitive equilibrium surplus for the institution that yields the highest possible level of total surplus. If an institution reaches 100% efficiency by this definition, then it has realized the maximum amount of total surplus for *any institution*. This distinction is particularly important when considering a command and control type mechanism to regulate water transfers. These markets typically reach average efficiencies of almost 100% quickly by the first definition and show little variation. However, because of the fixed constraints, the amount of available surplus is drastically lower so although they perform well given the constraints, there may be other more flexible institutions that can increase overall welfare.

Our results showed that although the 3PBuyer institution had the potential for high efficiencies by *both* definitions, free riding and strategic behavior eroded most of the potential gains. The RevTax experiments were able to realize high levels of efficiency by the first definition and still realize levels of surplus comparable to the 3PBuyer market. Although we

have pointed out issues such as the distribution of surplus and equity that need further attention, a tax on water transfers as proposed by the California Model Water Transfer Act [5] offers a promising alternative as it offers high levels of efficiency and market stability but is still more flexible than fixed limits on water transfers.

One unmentioned aspect of the tax option, however, that needs further research is the arbitration mechanism. In this research, we assumed a perfectly informed neutral arbitrator to distribute monetary compensation to injured parties. Of course, in the real world, this is not the case. Third parties damaged by a water transfer have an incentive to misrepresent damages in order to receive higher amounts of compensation. Finally, this paper evaluates third party compensation in a market for short-term water leases. In the long-run, continued third party compensation minimizes any incentives to engage in some other, more productive economic behavior. A policy that includes third party compensation for long-term transfers might benefit from a sunset provision that phases this compensation out over time.

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ENDNOTES

- ¹ A non-consumptive or non-rival water use includes any activity that derives a benefit (pecuniary or non-pecuniary) from the water without actually consuming it. For example, water consumed in an agricultural region may stimulate local economic growth and water flowing instream may provide water quality and environmental benefits.
- ² The payment to the Palo Verde community (Vogel, 2002) could be loosely interpreted as an example of such a transaction. In that case, the community received \$6 million as compensation for local economic damages. The efficiency and equity implications of this particular payment are an empirical question beyond the scope of this paper.
- ³ We assume that the tax rate is set at the start of the water year and remains fixed until the following year.
- ⁴ Although the statutory incidence of the tax falls on sellers, the economic incidence will be shared by both buyers and sellers.
- ⁵ The induced values for all agents are available from the authors upon request.
- ⁶ Throughout the analysis in this paper, we drop the results from periods 1 and 2 to minimize learning effects unless otherwise noted.
- ⁷ We also modeled learning using *Period* and *Period*²; this yields the same conclusions.
- ⁸ The competitive equilibrium surplus of the *UnitTax* and *RevTax* treatments differs slightly due to the discrete nature of the supply and demand step functions.
- ⁹ Table 3 reports the efficiency comparison only for dry years. A comparison for wet years yields similar results.
- ¹⁰ Efficiency would require that consumption be subsidized at locations with third party impacts. The subsidy rate would differ by location based on marginal third party impacts. The subsidy would be identical to the competitive equilibrium prices in the *3PBuyer* treatment.
- ¹¹ It is possible that these small deviations are at least partially to the discrete, step-wise nature of the supply and demand functions.

Table 1. Summary statistics: Efficiency for each treatment

Treatment	All Periods (excl. Per 1-2)				
	N	N > 90%	Mean	Std Dev	Median
3PBuyer	88	26 (30%)	86.0	7.8	86.4
RevTax	108	77 (71%)	92.1	6.4	93.3
UnitTax – all	100	39 (39%)	85.1	10.4	88.3
UnitTax – drop UnitTax05	84	39 (46%)	87.6	8.3	89.8
	Only Periods ≥ 10				
	N	N > 90%	Mean	Std Dev	Median
3PBuyer	40	15 (38%)	87.8	5.8	87.4
RevTax	60	48 (80%)	93.6	4.9	94.3
UnitTax – all	52	26 (50%)	89.3	5.7	90.1
UnitTax – drop UnitTax05	44	26 (59%)	90.9	3.8	91.1

Table 2. Restricted maximum likelihood estimates from mixed effects model for efficiency

Variable	Coefficient	Standard Error
Intercept	87.54 ***	2.25
3PBuyer	1.26	3.10
RevTax	6.87 **	3.08
Dry Year	-0.02	0.76
Periods 3 to 10	-5.08 ***	0.77

Dependent variable: Efficiency in each period (excludes periods 1-2). For purposes of brevity, the group-specific random effects are not included in this table. Number of observations: 296. Model significance (Pr>Chi-square): <.0001. *** = significant at 1%, ** = significant at 5%.

Table 3: Efficiency comparison for dry years^a

Treatment	Competitive Equilibrium Surplus	Average Realized Surplus	Average Efficiency^b	Avg. Efficiency Relative to Maximum Possible Surplus^c
3PBuyer	7626	6603	87%	87%
RevTax	6872	6261	91%	82%
UnitTax ^d	6704	5788	86%	76%

^a Excludes periods 1 – 2.

^b Average realized surplus for each treatment divided by competitive equilibrium surplus for that treatment.

^c Average realized surplus for each treatment divided by competitive equilibrium surplus for *3PBuyer* treatment (7626).

^d Includes *UnitTax05* session. If this session is excluded, average realized surplus increases to 5985 and the two efficiency measures increase by about three percentage points.

Table 4. Summary statistics: Prices for each treatment

Treatment	Wet Years			Dry Years		
	Comp. Equil. Price	Mean Price	Std. Dev.	Comp. Equil. Price	Mean Price	Std. Dev.
3PBuyer	54	48.1	2.4	121	99.9	7.9
RevTax	51	53.8	1.5	114	114.6	2.4
UnitTax ^a	51	57.1	3.3	116	118.7	4.5

^a Dropping UnitTax05 decreases the mean price by about 1 and decreases the standard deviation by about 0.7.

Table 5. Actual third party contributions as a percent of the competitive equilibrium contribution

Node	Mean	Std Dev	Median
Buy-1	45.5%	33.9%	45.5%
Buy-2	68.7%	48.0%	62.5%

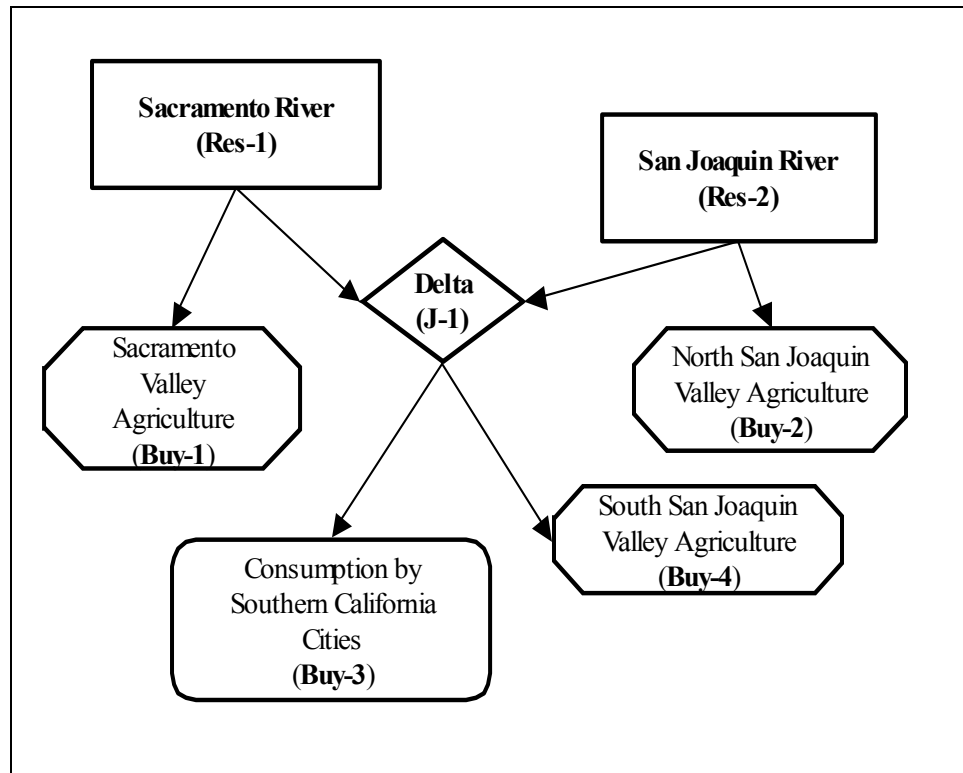
Table 6. Restricted maximum likelihood estimates from mixed effects model for percent of competitive equilibrium third party contributions

Variable	Coefficient	Standard Error
Intercept	78.7 ***	11.4
Node Buy-1	-23.7 ***	4.6
Dry Year	-31.5 ***	4.6
Periods 3 to 10	12.0 ***	4.6

Dependent variable: Percent of competitive equilibrium contributions by third party in each period (excludes periods 1-2). For purposes of brevity, the group-specific random effects are not included in this table. Number of observations: 176. Model significance (Pr>Chi-square): <.0001.

*** = significant at 1%.

Figure 1: Laboratory water network



The labels in parentheses correspond to the location names used in the experiment.